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INVESTIGATION OF THE CLIMATE IMPACT ON THE SNOW AND ICE THICKNESS IN LAKE VANAJAVESI, FINLAND
Arctic climate response to regional aerosol emission changes between 1980 and 2005

Acosta Navarro, J. C.¹, Varma, V.², Riipinen, I.¹, Seland, Ø.³, Kirkevåg, A.³, Struthers, H.⁴, Iversen, T.⁵, Hansson, H.-C.¹, Ekman, A. M. L. ²

¹ Department of Environmental Science and Analytical Chemistry (ACES) and Bolin Centre for Climate Research, Stockholm University, Sweden, Juan-Camilo.acosta@aces.su.se
² Department of Meteorology and Bolin Centre for Climate Research, Stockholm University, Sweden
³ Norwegian Meteorological Institute, Oslo, Norway
⁴ National Supercomputer Centre, Linköping, Sweden

Emissions of aerosols and their precursors have drastically decreased at northern hemisphere mid-latitudes during the past three decades due to air quality regulations. Contrastingly, emissions in the northern hemisphere tropics and subtropics have increased as a consequence of the economic growth and development. We assess the influence of these regional emission changes on climate with a particular focus on the Arctic using the fully coupled ocean-atmosphere climate model NorESM₁. Different mechanisms that couple the localized forcing with the corresponding temperature response are also suggested. European emission reductions of SO₂ that have taken place since the 1980’s, seem to have had a disproportionately large effect on the Arctic climate compared to the rest of the northern hemisphere. Emission changes of other aerosol types and over other regions such as North America and Asia appear to have had a much smaller influence on recent Arctic climate change.

Locally, the Arctic warming due to the decreased SO₂ in Europe exceeds 0.5°K. The main reasons for this strong remote temperature response are: 1) an increase in poleward oceanic and atmospheric heat transport into the Arctic cap during the summer half of the year; and 2) a local summertime increase in absorbed solar radiation at the surface caused mainly by sea ice and snow cover reduction. Part of the excess in energy gained during the summer by the Arctic ocean is returned to the atmosphere during the winter half of the year, causing the strongest seasonal warming during this months.

Reference:
INVESTIGATIONS OF BVOC-SOA-CLIMATE FEEDBACKS VIA INTERACTIVE BIOGENIC EMISSIONS USING NorESM

K. ALTERSKJÆR¹, J. E. KRISTJÁNSSON¹, A. GRINI², T. IVERSEN¹, A. KIRKEVÅG², D. OLIVIÉ², M. SCHULZ², and Ø. SELAND²

¹Department of Geosciences, University of Oslo, Oslo, Norway.
²Norwegian Meteorological Institute, Oslo, Norway

Keywords: BVOC, SOA, NorESM, climate feedback.

INTRODUCTION

Climate feedbacks represent a large source of uncertainty in future climate projections. One such feedback involves a change in emissions of biogenic volatile organic compounds (BVOCs) under global warming and a subsequent change in radiative effects of clouds and aerosols. Parts of the atmospheric BVOCs will oxidize in the atmosphere, which may reduce their volatility enough to form secondary organic aerosols (SOA). A changed SOA load will affect cloud radiative properties through aerosol-cloud interactions (ACI) and therefore act to reduce or enhance the temperature change resulting from greenhouse gases alone.

METHODS

In order to study this effect, a development version of the Norwegian Earth System Model (NorESM; Bentsen et al., 2013) has been extended to include explicit atmospheric particle nucleation and a treatment of SOA based on work Makkonen et al. (2014). Biogenic sources of monoterpene and isoprene are interactively calculated by the Model of Emissions of Gases and Aerosols from Nature (MEGAN), version 2.1 (Guenther et al., 2012), incorporated into the Community Land Model, version 4.5 (Oleson and Lawrence, 2013). Monoterpene and isoprene are oxidized by O₃, OH and NO₃ to form SOA with a yield of 15 % and 5 % respectively. It is assumed that 50 % of the product from monoterpene ozonolysis is of low enough volatility to nucleate new particles. The remaining oxidized BVOCs condensate onto pre-existing particles.

The model improvements include three new tracers to account for both SOA and the BVOCs. This allows for transport of both SOA and precursor gases, making it possible for SOA to form above the surface layer of the model. The new SOA treatment also changes the size distribution of most model aerosols due to condensation.

CONCLUSIONS

Preliminary results from 6-year simulations with prescribed sea surface temperatures show that the present-day emissions of both isoprene (435.9 Tg/yr) and monoterpenes (121.4 Tg/yr) are within the range found in other studies. The resulting SOA production is on the order of 77 Tg/yr, also within the range found by others, but on the high side. The global annual atmospheric burden of SOA is on the order of 1.0 Tg. A fraction of 4.5% of the produced SOA is nucleated into particles, while the remainder forms condensate. In the current set-up, emissions of both monoterpene and isoprene are slightly higher pre-industrially than in present day, which seems to be due to large land use changes. In regions of small land use changes, the change in 2 m air temperature dominates, with high air temperatures corresponding to
high BVOC emissions. An estimate will be made of the change in cloud radiative properties from pre-industrial times to present caused by the change in BVOC emissions and resulting change in SOA burden.

ACKNOWLEDGEMENTS

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REFERENCES


Implementation of state-of-the-art ternary new particle formation scheme to the regional chemical transport model PMCAMx-UF in Europe

E. Baranizadeh1, B. N. Murphy2,3, J. Julin2,3, C. L. Reddington4, S. Falahat2,3, C. Fountoukis5, S. N. Pandis5, H. Vehkamäki6, A. Laaksonen1, K. Lehtinen1, and I. Riipinen2,3

1Department of Applied Physics, University of Eastern Finland, POB 1627, 70211 Kuopio, Finland
2Department of Environmental Science and Analytical Chemistry, Stockholm University, Stockholm, Sweden
3Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden
4Institute for Climate and Atmospheric Science, School of Earth and Environment, University of Leeds, UK
5ICE-HT FORTH, Patras, Greece
6Department of Physics, P.O. Box 64, University of Helsinki, 00014, Helsinki, Finland

Keywords: Number concentration, new particle formation, PMCAMx-UF, ACDC

INTRODUCTION

Atmospheric new particle formation (NPF) has received increasing attention due to its possible impact on climate and human health. The number of submicron particles is especially important because of their ability to act as nuclei for the formation of cloud droplets and thus modify cloud properties. We use the three-dimensional chemical transport model PMCAMx-UF (Jung et al., 2010) to simulate both the number and mass of chemically speciated particles over Europe for May 2008. The aerosol size distributions are discretized as 41 size bins covering the diameter range 0.8 nm to 40 μm. In the previous applications of the model, the nucleation processes have been simulated based on semi-empirically scaled parameterization of Napari et al. (2002) for ternary H₂SO₄-NH₃-H₂O nucleation and the parameterization of Vehkamäki et al. (2002) for binary H₂SO₄-H₂O nucleation.

METHODS

In this work we have updated the model by replacing the semi-empirical ternary nucleation scheme with a look-up table generated by the Atmospheric Cluster Dynamics Code (Olenius et al., 2013), which calculates the cluster evaporation rates using state-of-the-art quantum chemistry methods. The look-up table contains the rates as a function of relative humidity, temperature, condensation sink and the NH₃ and sulfuric acid concentrations, and is thus a true first-principles approach to model NPF by sulfuric acid, ammonia and water.

CONCLUSIONS

The predicted vertical profiles of particle number concentrations (N) are shown together with the observed data collected during the LONGREX-EUCAARI Campaign in Figure 1. We used the updated PMCAMx-UF to simulate particle number concentration during May 2008 during which the EUCAARI-LONGREX campaign was carried out providing observed vertical profiles of aerosol number concentrations using two research aircraft (DLR and BAe). Vertical profiles of particle number concentrations show that predicted concentrations of small particles are within one order of magnitude of the aircraft measurements (Figure 1-a and b). Regardless of the NPF scheme, the predicted Aitken- and accumulation mode number concentrations are in similar agreement with the observational data throughout the atmospheric column, while the concentrations of smaller particles are somewhat over-predicted by the ACDC NPF scheme. Encouragingly, the updated PMCAMx-UF with the ACDC-based NPF scheme captures the trends in the vertical profile of the Aitken mode within the boundary layer. Our results show that implementing a H₂SO₄-NH₃-H₂O NPF scheme based on first-principles theory to a large-scale model is a promising alternative to semi-empirical approaches in the description of particle formation.
Figure 1. Vertical profiles of measured (black) and predicted (colour) particle number concentrations for the size ranges: (a) and (b) Larger than 4 nm ($N_4$) measurements collected by Falcon and BAe 146, respectively, (c) larger than 10 nm ($N_{10}$) measurements collected by Falcon 20, (d) and (e) 160-1040 nm ($N_{160-1040}$) measurements collected by Falcon and BAe 146, respectively, during May 2008. Red and blue lines show the predicted particle number concentrations by the PMCAMx-UF model using ACDC-based formation rates and scaled Napari new particle formation scheme, respectively. The (red, blue and black) lines show the median values of data points within each model layer, the error bars and grey shading indicate the values between 25-th and 75-th percentiles of the model and observations, respectively. Concentrations are given at ambient temperature and pressure.

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REFERENCES


HOW WELL DO MESOSCALE MODELS PERFORM FOR BOUNDARY-LAYER PROFILES IN HIGH ARCTIC CONDITIONS?

E. BATCHVAROVA1,2, SE GRYNING1, H KIROVA-GALABOVA2, H. SKOV3 and LL SØRENSEN3

1Technical University of Denmark, DTU Wind Energy, Roskilde, Denmark
2National Institute of Meteorology and Hydrology-BAS, Sofia, Bulgaria
3Aarhus University, Department of Environmental Science, Roskilde, Denmark

Keywords: WRF model, evaluation, radio-soundings, high Arctic

ABSTRACT

Main activities of DTU within CRAICC comprised ceilometer measurements (started in 2010 and is still running), two experimental two-week campaigns with aerological radiosoundings (summer period in 2011 and winter period in 2012). A number of runs with the Weather Research and Forecasting (WRF) model version 3.4.1 using different model configurations for Station Nord (81.65N, 16.65W) have been made.

30 radio soundings for the Arctic spring (March 3 – 18, 2012) and 25 radio soundings for the summer period (July 25 – August 05, 2011) were carried out for the evaluation of model simulations. The US NCEP Final Analyses (FNL) with 1x1 degree spatial and 6 hours temporal resolution was used to initialize the model. The sensitivity to the vertical and the spatial resolution was investigated by running the model in two configurations (25 vertical levels and 4 km grid step, 42 vertical levels and 1.33 km grid step). WRF was additionally run with two planetary boundary layer schemes: the Mellor-Yamada-Janjic (MYJ) with local vertical closure and the non-local Yonsei University scheme. Temporal evolution of planetary boundary development in the summer period was documented by up to 4 sounding per day (00, 06, 12, 18 GMT). The MYJ scheme resolved the measurements with a correlation coefficient above 0.7 (except for the zonal component of the wind). The variability of the correlation coefficient with height showed good agreement above 80 m for temperature, above 150 m for relative humidity and for all levels for wind speed. Direct comparison of model and measured data revealed that the model simulated the vertical profiles of the studied parameters relatively better in cloudy sky conditions, compared to clear skies.
Linking sources of SLCFs to radiative forcing and Arctic climate response

T.K. Berntsen¹,², M. Sand¹, J. Langner³, M. Flanner⁴, K. Von Salzen⁵ and D. Victor⁶

¹Center for International Climate and Energy Research—Oslo (CICERO), 1129 Blindern, 0318 Oslo, Norway
²Department of Geosciences, University of Oslo, 1047 Blindern, 0316 Oslo, Norway.
³Swedish Meteorological and Hydrological Institute, 601 76 Norrköping, Sweden
⁴Climate and Space Sciences and Engineering, 2455 Hayward Street, Ann Arbor, Michigan 48109, USA
⁵Canadian Centre for Climate Modelling and Analysis, Environment Canada, Victoria, British Columbia V8W 3R4, Canada.
⁶School of Global Policy and Strategy, University of California at San Diego, 9500 Gilman Drive, La Jolla, California 92093, USA.

Keywords: Short-lived Climate Forcers, Arctic climate change

INTRODUCTION

There is growing scientific and political interest in the impacts of climate change and anthropogenic emissions on the Arctic. Over recent decades temperatures in the Arctic have increased at twice the global rate, largely as a result of ice–albedo and temperature feedbacks (Hartmann et al., 2013; Screen and Simmons, 2010; Stroeve et al., 2012; Pithan and Mauritsen, 2014). Although deep cuts in global CO₂ emissions are required to slow this warming, there is also growing interest in the potential for reducing short-lived climate forcers (SLCFs) (UNEP, 2011; Shindell et al., 2012). Politically, action on SLCFs may be particularly promising because the benefits of mitigation are seen more quickly than for mitigation of CO₂ and there are large co-benefits in terms of improved air quality. Sand et al. (2015) is one of the first studies to systematically quantify the Arctic climate impact of regional SLCFs emissions, taking into account black carbon (BC), sulphur dioxide (SO₂), nitrogen oxides (NOₓ), volatile organic compounds (VOCs), organic carbon (OC) and tropospheric ozone (O₃), and their transport processes and transformations in the atmosphere.

METHODS

Using several chemical transport models we perform detailed radiative forcing calculations from emissions of these species. To estimate the Arctic surface temperature we apply regional climate sensitivities (RCSs), the temperature response per unit of radiative forcing for each SLCF (Shindell and Faluvegi, 2009; Shindell, 2012; Collins et al., 2013; Flanner, 2013). The RCSs are defined in four broad latitude bands (60-90°N, 28-60°N, 28°S-28°N, 90-28°S) to account for contributions by local and remote forcing to surface temperature changes in each band.

CONCLUSIONS

This study extends the scope of previous works (Quinn et al., 2011; Quinn et al., 2008) by including more detailed calculations of Arctic radiative forcing and quantifying the Arctic temperature response. We find that the largest Arctic warming source is from emissions within the Asian nations owing to the large absolute amount of emissions (Figure 1). However, the Arctic is most sensitive, per unit mass emitted, to SLCFs emissions from a small number of activities within the Arctic nations themselves. A stringent, but
technically feasible mitigation scenario for SLCFs, phased in from 2015 to 2030, could cut warming by 0.2 (±0.17) K in 2050.

Figure 1 | Model-mean annual Arctic equilibrium surface temperature response. Each bar represents the different emission sectors for each source region specified on the x axis. The emission sectors are, in order from left to right: domestic, energy/industry/waste, transport, agricultural waste burning, grass/forest fires, and flaring. The black dots are the total temperature response and the crosses represent the model spread (of total response) as a root-mean-square error. The doughnuts illustrate how much of the Arctic warming (red) and cooling (blue) comes from forcing within the Arctic (solid fill) versus outside the Arctic (striped).

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REFERENCES


Pithan, F. & Mauritsen, T. Arctic amplification dominated by temperature feedbacks in contemporary
Quinn, P. K. et al. The Impact of Black Carbon on Arctic Climate (Arctic Monitoring and Assessment Programme (AMAP), 2011).
SEA SPRAY AEROSOL STUDIES

M. BILDE

Department of Chemistry, Aarhus University Langelandsgade 140, DK-8000 Aarhus C, Denmark

Keywords: sea spray, ccn, sea surface microlayer, coated particles

INTRODUCTION

Sea spray aerosol presents a major source of aerosol particles to the atmosphere and sea spray aerosols affect climate directly by scattering and absorption of radiation and indirectly via the ability of sea spray aerosol to act as cloud condensation nuclei (IPCC 2013).

The so-called sea surface microlayer (SML) is the thin upper layer of the ocean forming a boundary between the ocean and the atmosphere. The SML is rich in surface active substances and is believed to play an important role for the chemical composition and properties of sea spray aerosol. Knowledge about the SML and its impact on sea spray aerosol is however limited.

This presentation provides an overview of lab and field experiments performed during the CRAICC project at Aarhus University and presents plans for future work.

METHODS

A sea spray tank (King et al. 2012) was used for simulation of sea spray generation using either a plunging jet or aeration through a diffuser. A series of equipment was used for characterization of the resulting sea spray aerosol: Scanning mobility particle sizer for determination of size distributions, Cloud condensation nucleus counter for cloud forming ability, thermodenuder for studies of volatility.

During a series of laboratory experiments the effects of surface active coatings of saturated and unsaturated fatty acids on the cloud forming ability of particles consisting of sigma sea salt were investigated.

During a field campaign in the Bay of Aarhus in spring of 2015 samples bulk water as well as sea surface microlayer samples were transported to the Chemistry Department and studied using the sea spray tank.

RESULTS

A kappa value of ~0.9 for particles consisting of sigma sea salt was derived. For particles coated with either palmitic, stearic, palmitoleic or oleic acids the kappa value in general increased with increasing core size for a given coating thickness, consistent with the kappa addition rule assuming a kappa value of zero for the fatty acids. Some deviations were observed and will be discussed (Nguyen et al. 2016).

Preliminary results from the field campaign show very little variation in surface tension and only slight deviation between subsurface water and the SML. Bulk sea water samples were spiked with SML seem to result in a small increase in organic share in the aerosol phase as indicated by volatility measurements, while the trend is unclear in CCN measurements.

Based on experience with the sea spray tank (King et al. 2012) a new tank has been designed and is currently under construction. The new tank will be presented as will ideas for future work.

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REFERENCES


IN-SITU QUANTIFICATION OF THE LINKS BETWEEN PHOTOSYNTHETIC EFFICIENCY, AEROSOL PRECURSORS, CONDENSATION SINK AND 3-10 NM PARTICLES IN A BOREAL FOREST

J.K. BÄCK¹, A. LINTUNEN¹, J. ATHERTON¹, F. XAUSA², L. LINDFORS¹, A. PORCAR-CASTELL, J¹. AALTO¹, T. NIEMINEN², T. PETÄJÄ² P. HARI¹ & M. KULMALA²

¹Department of Forest Sciences, University of Helsinki, 00014 Helsinki, Finland
²Dept. of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland.

Keywords: monoterpane emissions, photosynthetic recovery, chlorophyll fluorescence, nucleation, Scots pine shoots

INTRODUCTION

A clear seasonal pattern exists in atmospheric new particle formation in boreal regions: in spring the events occur in >50% of the days, while in summer the probability is considerably lower. Dal Maso et al (2007, 2009) discovered that the photosynthetic recovery period and onset of plant activity coincide with high numbers of events. However, the mechanisms behind the spring peak in new particle formation events has so far not been fully explained.

Conifer forests produce copious amounts of volatile organic compounds (VOCs) (e.g. Hakola et al 2006, Rinne et al 2009), of which most important for atmospheric chemistry perspective are the mono- and sesquiterpenes. Under ‘normal’ conditions (i.e. summertime) a simple exponential fit to temperature is a good proxy for Scots pine monoterpane emissions, which at those times largely originate from evaporation from storage pools. However, in springtime the frequently measured ‘monoherpene bursts’ from Scots pine foliage were linked to the photosynthetic recovery (Aalto et al 2015), and they were clearly originating from recently synthesized monoterpenes.

This study explores the relationships between the recovery of springtime photosynthetic efficiency, emissions of biogenic volatile organic compounds (particularly monoterpenes), condensation sink (CS), small aerosol particles (N3-10nm) and light and temperature conditions, using in situ measurements from SMEAR II station between years 2009-2014. We hypothesized that the monoterpane bursts in springtime could be linked to the stress that plants undergo during spring when air temperatures are low and photosynthetic machinery down after winter, but solar radiation is already high.

METHODS

The relationships between Scots pine monoterpane emissions, the maximum quantum yield of photochemistry (FiPmax), and new particle formation (CS and N3-10nm) were analysed. In situ data was obtained from the Station for Measuring Ecosystem-Atmosphere Relations (SMEAR) II located in Hyytiälä, Southern Finland (61° 51’ N, 24° 17’ E, 181 m a.s.l.). Data was filtered for separating out the clear pollution episodes, and also for the use of clear sky conditions only.

VOC emissions and gas exchange measurements

Monoterpane emission measurements from shoots of mature Scots pine were performed with a proton transfer reaction quadrupole mass spectrometer (PTR-Q-MS, Ionicon Analytik GmbH, Austria) connected to several Teflon-coated dynamic shoot enclosures located at the top of the canopy (for details, see Kolari et al 2012, Aalto et al 2015). Monoterpenes were identified as M137 (amu+1), and measurements were done on a continuous basis. Air temperature (PT100 or copper-constantan thermocouple) and photosynthetically active photon flux density (LI-COR LI-190 quantum sensor) were recorded at 5-s interval from inside the
enclosures. The data was available for the years 2007-2014, however we selected smaller datasets for the analysis from 2010 and 2013, with the best quality and temporal coverage.

**Fluorescence**

The maximum quantum yield of photochemistry (FiPmax) obtained during night time was used as a proxy of the seasonal dynamics in needle level photosynthetic activity. Time series of FiPmax were derived from Monitoring Pulse Amplitude Modulated (PAM) fluorescence measurements (Porcar-Castell 2011) (Heinz Walz, GmbH, Germany). Measurements were obtained with 4-5 independent measuring heads placed at the top branches of three Scots pine trees. FiPmax represents the maximum fraction of absorbed light that can be used by photosynthesis, with an optimal value of ~0.83 under optimal conditions. Reductions in FiPmax can be caused by stress events (e.g. cold temperatures, high light) and reflect also the underlying seasonal pattern of photosynthetic activity.

**New particle formation: Condensation sink, particle number concentrations**

The condensation sink (CS) and small particle number concentration (N3-6nm) data was obtained from the Differential Mobility Particle Sizer (DMPS) with 10 minutes time resolution, while the black carbon (BC) data was collected by an aethalometer, respectively. BC was used as a tracer for the polluted air masses, and periods with BC higher than 250 ng/m3 were removed from the analysis. This step was necessary to remove parts of the data in which CS variation was more dependent on pollution episodes rather than biogenic activity within the boreal forest.

Since the attention was focused on the stress that plants undergo during high amount of light at low temperatures, sunny days were selected in order to investigate the relationship between FiP and CS. Such selection was obtained by using the ratio of measured/theoretical maximum global radiation to remove days of cloudiness for which these ratio values were lower than 0.5.

**RESULTS**

During the transition time between winter and spring the ecosystems are going through a gradual change from winter rest period to summer active growth period. We discovered that there are clear relationships between the daily max irradiation (PAR/UV) or FiPmax and new particle formation (NPF) event days in spring (Figs 1 and 2). Surprisingly, a less evident relationship was discovered between diurnal temperature change (Tmax-Tmin) and spring NPF event days (Fig 1c, 2c). High N3-10nm was clearly linked to high light and low temperatures as the largest N3-10nm were observed on days with high PAR/UVB and minimum temperature below zero Celsius (Fig 2), whereas high CS was not (Fig 1).

The daily variations in light and temperature affect the monoterpene emissions and follow-up chemistry (seen in CS and particle numbers). When further analysing the temperature and PAR relationship with emissions, we found a correlation between PAR levels and 1-yr-old shoot monoterpene emissions, but this correlation was very different for different temperature bins (Fig 3). When analysing the photochemical yield, we can differentiate between a photo-typical and a photo-atypical behaviour of emissions. The photo-atypical phenomenon is clearly seen in low temperatures when the high emissions are clearly higher than expected due to high-light induced temporary stress.
Figure 1. Relationship between diurnal minimum temperature, and diurnal max PAR (a), diurnal max UV-B (b), diurnal temperature change (c) and diurnal maximum quantum yield of photochemistry (d) in spring measurements in years 2006-2014. Point size indicates the relative condensation sink at the time of measurements. Colour coding refers to clear event days (1a, black circles), other event days (1b, blue circles) and non-event days (grey circles). R value and a linear regression curve are indicated in each figure for the 1b event days.

Figure 2. Relationship between diurnal minimum temperature and diurnal max PAR (a), diurnal max UV-B (b), diurnal temperature change (c) and diurnal maximum quantum yield (d) in spring measurements in years 2006-2014. Point size indicates the relative 3-10 nm particle number concentration at the time of measurements. Colour coding refers to clear event days (1a, black circles), other event days (1b, red circles) and non-event days (grey circles). R value and a linear regression curve are indicated in each figure for the 1b event days.
Fig 3. Monoterpene emissions in 2013 measured with pine shoot enclosure in relation to PAR levels (left) and maximum quantum yield of photosynthesis (right). Color coding refers to daily median temperature during measurements.

Further, the spring-time low photochemical yield seems to be connected to high particle number concentrations (Fig 4). This is most evident when temperatures are below +5 C, similarly as the emission bursts (Fig 3). We discovered a good correlation between the number of small particles and photochemical yield (Fig 4), showing a similar a-typical behaviour in low temperatures. In spring, the high incident emission bursts indicate stress due to a combination of low temperatures, relatively high light and down-regulation of photochemistry.

Fig 4. Particle number concentration (3-10nm in diameter size) as a function of photochemical yield (here: Φp) with temperature in color bar for clean air mass (BC>250ng/m3) in spring-summer 2010. Higher number of particles is observed at low temperatures, suggesting higher stress-related emissions during spring recovery period.

CONCLUSIONS

From the large in situ dataset of SMEAR II it is possible to conclude that the spring transition time is in many respects very different from other times of the year. During the transition period the correlations between ecosystem activity and atmospheric processes are different from ‘normal’ summer conditions, indicating that a ‘photo-atypical’ behaviour is often needed for strong nucleation. As fluorescence indices
reflecting the photosynthetic activity very accurately are easily retrieved from satellite data, this opens up new possibilities for upscaling with remote sensing for defining the critical periods for nucleation over large areas.

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REFERENCES


A thermodynamic description for the predeliquescence of atmospheric aerosol particles

D. CASTAREDE$^{1,2}$ and E.S. THOMSON$^1$

$^1$ Department of Chemistry and Molecular Biology, Atmospheric Science, University of Gothenburg, SE-412 96, Gothenburg, Sweden.
$^2$ Observatoire MidiPyrenees, University of Toulouse (Paul Sabatier, Toulouse III), France.

Keywords: DELIQUESCENCE, PRE-DELIQUESCENCE, KOHLER THEORY, INTERMOLECULAR FORCES

INTRODUCTION

The phase state of atmospheric particulate is particularly important to atmospheric processes and aerosol radiative forcing remains one of the largest uncertainties in climate predictions (Stocker et al., 2013). That said, precise phase behavior is difficult to quantify in the atmospheric context and observations have shown that pre condensation of water below predicted saturation values can occur (Cheng et al., 2015). In this study we propose a revised approach to understanding the transition from solid salt particles to water droplets. At a certain deliquescence relative humidity DRH below the saturation point of water vapor, salt particles are suddenly dissolved resulting in water droplets of brine composition. This deliquescence phenomenon explains the occurrence of water droplets at relative humidities below water saturation and in the atmosphere is captured by Köhler theory which describes a very sudden transition from solid salt to solution droplet. This Köhler model incorporates two ideas, mixing entropy (Raoults law) and droplet geometry (Kelvin effect) and provides a simple description of dissolving soluble particles. It has remained the tool of choice for understanding atmospheric processes and condensation nucleation. However, given the observations of precondensation that is not predicted by Köhler theory, we suggest a theoretical refinement by considering the effect of interfacial intermolecular forces on the solvating system (Hansen-Goos et al., 2013). Instead of the sudden transition predicted by Köhler theory, we demonstrate a model of a salt particle being gradually engulfed and dissolved by a growing brine layer like that presented in Figure 1.

![Figure 1: Representation of the system considered](image-url)
RESULTS AND DISCUSSION

The refined Köhler equation shows that with the addition of intermolecular forces, a pre-condensation of water vapor occurs on the surface of salt particles at humidities below deliquescence. The results may help to explain observations of pre-condensation (pre-activation) seen in atmospherically relevant measurements and may help to improve the accuracy of models that use Köhler theory.

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REFERENCES


SUBMICRON PARTICULATE MATTER IN ICELANDIC DUST STORMS IN 2015

P. DAGSSON-WALDHAUSEROVA1,2,3, A.O. MAGNUSDOTTIR1, H. OLAFSSON2,4, and O. ARNALDS1

1Faculty of Environmental Sciences, Agricultural University of Iceland, Keldnaholt, Reykjavik, 112 Iceland.

2Faculty of Earth and Physical Sciences, University of Iceland, Reykjavik, 101 Iceland.

3Faculty of Environmental Sciences, Czech University of Life Sciences, Prague, 165 21 Czech Republic.


Keywords: ARCTIC DESERT, CLOSE-TO-ULTRAFINE NATURAL PARTICLES, VOLCANIC ASH, PM1

INTRODUCTION

Iceland has the largest area of volcaniclastic sandy desert on Earth where dust is originating from volcanic, but also glaciogenic sediments. Total Icelandic desert areas cover over 44,000 km² suggesting Iceland being the largest Arctic as well as European desert (Arnalds et al., 2016). Satellite MODIS pictures have revealed dust plumes traveling over 1000 km at times. The mean frequency of days with dust suspension was to 135 dust days annually in 1949-2011. The annual dust deposition was calculated as 31 - 40.1 million tons yr⁻¹ affecting the area of > 500,000 km², which places Iceland among the most active dust sources on Earth. Volcanic dust is distributed over local glaciers (about 4.5 million t annually) and surrounding oceans (6 – 14 million t annually). Studies that provide particulate matter (PM) mass concentration measurements during dust storms in Iceland are few and none of them deal with the size partitioning of the PM components. Generally, only few studies address levels and speciation of PM1 during dust storms elsewhere (Gomišček et al., 2004, Shahsavani et al., 2014). The PM1 fraction has considerable importance in relation to health because of high potential for entering the lungs (Colls and Tiwary, 2010). Moreover, submicron particles are more likely to travel further distances during the long range transport than larger particles (Mahowald et al., 2014). Here we presented a study on PM partitioning of volcanic dust during dust storms in Iceland, with emphasis on the fine dust fraction of PM1. Additionally, transverse horizontal profile of dust storms was estimated to determine the spatial extent of such storms in the terms of PM concentrations, dust load and visibility obtained from cameras.

METHODS

Two dust storms were measured in transverse horizontal profile about 90 km far from different dust sources in southwestern Iceland in the summer of 2015. Aerosol monitor DustTrak DRX 8533EP was used to measure PM mass concentrations corresponding to PM1, PM2.5, PM5, PM10 and the total PM15 at several places within the dust plume. Images from camera network operated by the Icelandic Road and Coastal Administration were used to estimate the visibility and spatial extent of measured dust events. A numerical simulation of surface winds was carried out with the numerical model HIRLAM with horizontal resolution of 5 km and used to calculate the total dust flux from the sources.
CONCLUSIONS

The in situ measurements of two moderate Icelandic dust storms in 2015 show that aeolian dust can be very fine. The study highlights that suspended volcanic dust in Iceland causes air pollution with extremely high PM$_1$ concentrations comparable to the polluted urban stations in Europe or Asia than reported dust event observations from around the world. The PM$_1$/PM$_{2.5}$ ratios are generally low during dust storms outside of Iceland, much lower than > 0.9 and PM$_1$/PM$_{10}$ ratios of 0.34-0.63 found in our study. It shows that Icelandic volcanic dust consists of higher proportion of submicron particles compared to crustal dust. The submicron particles are predicted to travel long distances. Moreover, such submicron particles pose considerable health risk because of high potential for entering the lungs. Icelandic volcanic glass has often fine pipe-vesicular structures known from asbestos and has high content of heavy metals. Previous measurements on the Maelifellssandur dust source revealed extremely high number concentrations of submicron particles, specifically in the size range 0.3-0.337 µm (Dagsson-Waldhauserova et al., 2014). The PM$_{2.5}$/PM$_{10}$ ratios of number concentrations were about 0.8, but the PM$_{2.5}$/PM$_{10}$ ratios of mass concentrations did not correspond to such high proportions as found during the Landeyjarsandur or Hagavatn dust storms in 2015. The measurements from the previous study were, however, obtained within a dust source while here we measured in some distance from the dust sources.

Common dust storms are of several hundred thousand tons of magnitude from relatively well defined main dust sources. Numerical simulations were used calculate the total dust flux from the sources as 180,000 - 280,000 tons in this study. The mean PM$_1$ (PM$_{10}$) concentrations inside of the dust plumes varied from 97 to 241 µg m$^{-3}$ (PM$_{10}$ = 158 to 583 µg m$^{-3}$). The extent of moderate dust events was calculated as 2.450 km$^2$ to 4.220 km$^2$ of the land area suggesting the regional scale of the events. Dust plumes reported here passed the most densely inhabited areas of Iceland. The mean frequency of dust events in Iceland is about 135 dust days annually, however health risk warnings for the general public are not being issued. The data provided stresses the need for such warning system and is an important step towards its development.

ACKNOWLEDGEMENTS

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REFERENCES


DUST EVENTS ON VATNAJÖKULL, ICELAND: COMPARISON BETWEEN MODEL RESULTS AND MEASUREMENTS

Monika Dragosics¹, Christine Groot Zwaaftink ², Finnur Pálsson ¹, Throstur Thorsteinsson ¹, Andreas Stohl ²

¹ University of Iceland, Institute of Earth Sciences, Reykjavík, Iceland; ² NILU - Norwegian Institute for Air Research, Kjeller, Norway

Correspondence to: mod3@hi.is

Key words: Iceland, dust, FLEXPART, albedo

INTRODUCTION

Dust events in Iceland considerably influence the surface albedo and subsequently the energy balance of glaciers such as Vatnajökull. Dust events on Vatnajökull based on model simulations are compared with meteorological data from the automatic weather stations (AWS) situated on Brúarjökull (NE Vatnajökull, Figure 1). Possible sources of dust origin are proglacial areas and sandy deserts which cover more than 22% of Iceland (Arnalds et al. 2016).

METHODS

A newly developed scheme for dust mobilization is used to estimate dust emission from these sandy deserts. Driven with these emissions, a Lagrangian dispersion model, FLEXPART, is used to calculate dust concentration and deposition. The model simulations facilitate to distinguish main source areas of dust transported to the glacier. Meteorological conditions at the source locations as well as flows induced by topography will affect the spatial distribution of dust on the glacier, and not all are resolved by the meteorological data from ECMWF used to run FLEXPART (resolution 0.2 degrees or about 22 km). We determined how important local effects are. Ground based data such as distributed snow samples from Vatnajökull with impurities were collected in October 2013 and 2015. Additionally, firn cores of about 8
meters depth from Brúarjökull (NE Vatnajökull), were taken in 2014 and 2015. The firn cores show pronounced dust layers in the years 2012, 2011, 2010 and 2008. These dust concentrations from firn cores and snow samples as well as time series of albedo measurements from automatic weather stations, were compared to model results. For this comparison we chose ablation seasons which are not influenced by volcanic eruptions. For these periods we explain variations in dust amounts and their spatial patterns. The main focus was on the year 2012 and its events on Brúarjökull.

Figure 2: MODIS image of Iceland on the a) 20.Mai 2012 (day 141) and b) 28.Mai 2012 (day 149) after a dust storm event visible on Brúarjökull (north-Vatnajökull)

CONCLUSIONS

On station B13, which is lower in elevation than B16 (1211m vs 1526m) dust deposition and concentration during events were always larger except event nr. 1.
On station B13 in 2010 11 dust events occurred, 4 main events and 6 smaller events. 10 of the 11 events are in correlation with albedo/AWS measurements.
On average a dust event on station B13 in 2012 is 4 days long, has a concentration between 6 and 80 µg/m³ and 1g/m² dust deposited during an event, where dry deposition in all cases except the first event exceeded. The Albedo is dropping from the maximum to the minimum value 0.26, and from start to end of the dust event 0.16. The average temperature during dust events is -2 degrees and the main wind direction in over 70% of the events is north. Precipitation occurring during events is 24mm.
Due to surface snow measurements on Vatnajökull in 2013 the areal dust distribution could be compared with the FLEXPART model output and shows a very good agreement. Most dust is deposited in the SW (Tungnaárfjökull) and NE (Brúarjökull) of the ice cap.

ACKNOWLEDGEMENTS

The study described in this manuscript was supported by NordForsk as part of the Nordic Centre of Excellence within the framework of CRAICC (Cryosphere-atmosphere interactions in a changing Arctic climate), which is a part of the Top-level Research Initiative (TRI): 

REFERENCES

INSULATION EFFECTS OF ICELANDIC DUST AND VOLCANIC ASH ON SNOW AND ICE

Monika Dragosics¹, Outi Meinander², Tinna Jónsdóttir¹, Tobias Dürig¹, Gerrit de Leeuw ²,³, Finnur Pálsson¹, Pavla Dagsson-Waldhauserová⁴,⁵,⁶, Throstur Thorsteinsson¹

¹ University of Iceland, Institute of Earth Sciences, Reykjavik, Iceland; ² Finnish Meteorological Institute, Helsinki, Finland; ³ Department of Physics, University of Helsinki, Helsinki, Finland; ⁴ Agricultural University of Iceland, Faculty of Environmental Sciences, Hvanneyri, Iceland; ⁵ University of Iceland, Faculty of Physical Sciences, Reykjavik, Iceland; ⁶ Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Department of Ecology, Prague, Czech Republic

Correspondence to: mod3@hi.is

Key words: Iceland, insulation, ash, dust, snow, albedo

INTRODUCTION

The properties of snow and ice on the surface of glaciers in Iceland are influenced by the deposition of dust (Arnalds et al. 2014) and, during volcanic eruptions, by volcanic ash. Icelandic ash and dust is mainly basaltic volcanic glass which is deposited in Iceland’s sandy deserts which cover an area over 22,000 km². Deserts of this composition are globally unique (Arnalds 2010). Several dust storms occur in Iceland every year with deposition of dust or ash on the ice caps (Arnalds et al. 2014) with varying amounts at different altitudes which influences their melting behaviour. These dust storms are as well volcanic in origin (Arnalds et al. 2013) but redistributed and deposited in the glacier forefield where it is mixing with glacial till. From the forefield it can be resuspended into the air by the action of wind and carried onto the glacier. In this paper, effective and critical thicknesses for Eyjafjallajökull (2010) ash are studied and compared with the help of outdoor and laboratory experiments. The effective thickness is the thickness when the material-covered ablation is maximized. The critical thickness is the thickness of the material covering the ice or snow where the ablation rate of the material-covered ice or snow equals that of clean snow or ice; more material will start to insulate. (Brock et al. 2007). The aim was to study the influence of ash layers of variable thickness, as would result from dust storms or eruptions and how they influence glacier surface mass balance, whether they insulate the ice or enhance melting. The thickness of dust layers in dust storms is rather thin and is expected to enhance melting, whereas during eruptions layers can be very thick.

METHODS

Four outdoor and laboratory experiments have been carried out at the Finnish Meteorological Institute (FMI), at Kumpula Kampus in Helsinki, Finland. These experiments contribute to a better understanding of insulation characteristics of ash and dust deposition on Icelandic glaciers.
### Table 1: Effective and critical thickness for different materials such as tephra, rock debris and dust

<table>
<thead>
<tr>
<th>Material</th>
<th>Effective thickness [mm]</th>
<th>Critical thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt St Helens (1980) ash</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>Hekla (1947) tephra</td>
<td>2</td>
<td>5.5</td>
</tr>
<tr>
<td>rock debris</td>
<td>~10</td>
<td>~15-50</td>
</tr>
<tr>
<td>Villarrica tephra (lapilli)</td>
<td>-</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Dust (largely organic matter)</td>
<td>-</td>
<td>1.33</td>
</tr>
<tr>
<td>Eyjafjallajökull ash (2010, 1 ϕ)</td>
<td>1</td>
<td>9-15</td>
</tr>
<tr>
<td>Eyjafjallajökull ash (2010, 3.5 ϕ)</td>
<td>≤1-2</td>
<td>13</td>
</tr>
</tbody>
</table>

1 Driedger (1981); 2 Kirkbride and Dugmore (2003); 3 Brock et al. (2007); 4 Adhikary et al. (2000)

### CONCLUSIONS

Our findings suggest that if the ash concentration on snow or ice is small, so the layer thickness is very thin, it has the potential to increase snow melt, but after a threshold thickness the insulation effect begins, and the snow melt is decreased compared to clean ice. The critical thicknesses are comparable and visible in all our experiments (table 1): in the experiments AoS (at the large deposition with 425g and 15 mm layer thickness), in the AoI experiment (deposition of 283 g, 120 ml, 33.7·10³ g m⁻² and 9-13 mm layer thickness), in the Roof 2015 experiment (A5 with 33.7·10³ g m⁻² and 9 mm layer thickness) as well as in the AiC experiment (425g deposition and 15 mm layer thickness). The effective thickness was reached for Hekla tephra at 2 mm and for Eyjafjallajökull ash at 1 mm, in the Roof experiment (at A3 with a deposition of 4.2·10⁴ g m⁻²). The 3.5 ϕ (90 μm) grain size needs a thickness of 13 mm to start insulating as observed in the Roof experiment (B5 with a deposition of 35·10³ g m⁻²). The Roof 2015 experiment shows as well that only 1-2 mm (B4) or smaller (B3, too thin layer to measure) are enough to enhance melt to a maximum for a grain size of 3.5 ϕ.

### ACKNOWLEDGEMENTS

The study described in this manuscript was supported by NordForsk as part of the Nordic Centre of Excellence within the framework of CRAICC (Cryosphere-atmosphere interactions in a changing Arctic climate), which is a part of the Top-level Research Initiative (TRI).

### REFERENCES


Arnalds O, Olafsson H, and Dagsson-Waldhauserova P (2014) Quantification of iron-rich volcanogenic dust emissions and deposition over the ocean from Icelandic dust sources. Biogeosciences, 11(23), 6623-6632.


ARCTIC SEA ICE EFFECTS ON AEROSOL PROPERTIES

E.-M. DUPLISSY¹, R. VÄÄNÄNEN², T. PETÄJÄ¹, V.-M. KERMINEN¹ and M. KULMALA¹

¹Division of Atmospheric Sciences, Department of Physics, University of Helsinki, P.O. BOX 64, 00014 University of Helsinki

Keywords: Aerosol distribution, Arctic sea ice, aerosol concentration, Arctic Oscillation.

INTRODUCTION

Arctic sea ice is declining rapidly (Stroeve, 2007). This will inevitably have influences on aerosol properties around the Arctic. Here we show preliminary results of how the aerosol size distribution and concentrations change at the SMEAR I station in eastern Lapland, Finland, when the measured air mass has spent 0 to 3 days above the sea ice.

METHODS

In order to quantify the effects of Arctic sea ice to the aerosol properties, we used aerosol size distribution data measured with the DMPS (Differential Mobility Particle Sizer), trace gas concentration data, Arctic sea ice concentration data from NSIDC (National Snow and Ice Data Center), daily Arctic Oscillation (AO) indices and HYSPLIT back trajectories. First, we removed all the days with less than 15 DMPS spectra and calculated the daytime mean spectra (09-15 local time) for those days with more than 10 spectra during the daytime. Then we removed all the data where the SO₂ concentration was above 75th percentile in order to get rid of the effect of Kola Peninsula sulphur pollution. We binned the data according to how many hours the air mass had been spent over sea ice with fraction >80%, sea ice with fraction >15%, open sea and land. For this, only data with more than 10 days in each bin was considered. Also, only trajectories which had spent >90% of their travel time north of 67.31°N (50 km south of SMEAR I) were considered.

RESULTS

Aerosol number concentrations were found to decrease with an increasing time the air mass spent over the sea ice (Fig. 1). This phenomenon was evident also when the effect of land was removed by excluding all trajectories which have spent more than 40 hours above land. The decrease was seen in all aerosol modes (nucleation, Aitken and accumulation modes), but it was strongest and most significant in total and Aitken mode particle concentrations. The bigger the sea ice fraction (>15% or >80%) was, the stronger was the effect. Interestingly, however, if the data was divided into three categories: AO≤-1.5, -0.5≤AO≤+0.5 and AO≥+1.5, the decrease in aerosol concentrations with increasing time over sea ice was most prominent in the strongly positive AO cases. The aerosol size distribution changed also with increasing time over sea ice (Fig. 2); on average the peak diameter changed -0.52 nm/h. The change in the peak diameter was strongest and most significant for cases where AO was close to zero and second strongest for strongly negative AO cases.

Since the particle number concentration and mean diameter both decrease with increasing time over sea ice, in the future the Arctic could be even cloudier due to the increasing number of CCN. This, in turn, changes the radiation balance of the Arctic. However, it is predicted, that the decreasing Arctic sea ice favours the negative phase of AO (Vihma, 2014) especially during the cold season. We also excluded the months with least sea ice (June, July, August and September) from the data and in this case, the changes in both concentration and diameter were negligible if AO was very negative. Hence, it is possible, that the changes in the number concentration or size distribution of aerosols are not very strong in the future and will not affect the cloudiness or the radiation balance greatly.
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REFERENCES


Figure 1 Total and modal aerosol concentration change (left panel) and the diameter change (right panel) when the trajectory has spent 0-78 hours above sea ice with fraction >80%. Only trajectories coming from north are considered. The dashed and dotted lines are linear regressions and their 50% prediction bounds, respectively. The black dots in the size spectrum are modal fits into each size bin, into which the linear regression has been made. The changes in concentration and diameter per hour and the R² values are given also. The white dashed line in the size spectrum plot is at 80 nm.
Ice Nucleation Chambers for CRAICC

J. Duplissy\(^1\), Q. Nguyen\(^2\), E.S. Thomson\(^3\), L. Ahonen\(^4\), M. Kulmala\(^4\), T. Petäjä\(^4\), M. Sipilä\(^4\), M. Bilde\(^2\) and E. Swietlicki\(^5\)

\(^1\)Helsinki Institute of Physics, University of Helsinki, 00014, Helsinki, Finland
\(^2\)Department of Chemistry and iNANO, Aarhus University, 8000 Aarhus, Denmark
\(^3\)Department of Chemistry and Molecular Biology, Atmospheric Science, University of Gothenburg, 41296, Gothenburg, Sweden
\(^4\)Department of Physics, University of Helsinki, 00014 Helsinki, Finland
\(^5\)Department of Physics, Lund University, Box 118, 222 11 Lund, Sweden

Keywords: Ice Nuclei Chamber, PINC, ZINC, ice nuclei, CRAICC

INTRODUCTION

The importance of ice crystals in clouds for our climate is manifold: Their presence, number and shape influences the optical properties of clouds, the formation of precipitation and their lifetime. All of these aspects have an impact on the radiation balance and therefore on climate. Within the CRAICC project (Cryosphere-atmosphere interactions in a changing Arctic climate) we aim to investigate the ice nuclei properties of aerosols present in the artic region by continuous measurements at different Nordic field stations.

METHODS

Two new ice nucleation chambers have been built based on the concept of the laboratory instrument ZINC (Zurich Ice Nucleation Chamber) and PINC (Portable Ice Nucleation Chamber), both being developed at ETHZ, Switzerland. The field instrument PINC has already successfully participated in a couple of laboratory campaigns (Chou et al, 2013; Kanji et al, 2013; Wex et al, 2014; Hiranuma et al, 2014) as well as in field campaign (Chou et al, 2011). Our improved PINC has two portable refrigerant compressors to directly cool the walls of the chamber without the use of an intermediate cooling liquid. In this configuration, the instrument is able to measure ambient ice nuclei (IN) concentrations at conditions as cold as -40°C and relative humidities exceeding water saturation. Our improved PINC has a longer ice nucleation chamber (1 meter) similar to the ZINC.

CONCLUSIONS

A successful collaboration between ETHZ and the CRAICC partners has led to technology transfer for the manufacture of the two Ice Nucleation Chambers. An inter-comparison prior to their first campaign is scheduled in autumn 2016. The status of the ice chambers, their operational field modes as well as their improvement will be presented during this meeting.

ACKNOWLEDGEMENTS

This work was supported by CRAICC, the Finnish Center of Excellence and the Swedish Research Councils

REFERENCES

Chou et al. (2011), Atmos. Chem. Phys., 11, 725-4738
Chou et al. (2013), Atmos. Chem. Phys., 13, 761-772
Kanji et al. (2013), Atmos. Chem. Phys., 13, 9097-9118
Wex et al. (2014), Atmos. Chem. Phys. Disc., 14, 22321–22384
Hiranuma et al. (2014), Atmos. Chem. Phys. Disc., 14, 22045–22116
THE CLIMATE RESPONSE TO BLACK CARBON IN THE NORESM

L. S. GRAFF\textsuperscript{1}, Ø. SELAND\textsuperscript{1} and T. IVERSEN\textsuperscript{1}

\textsuperscript{1} Norwegian Meteorological Institute, Oslo, Norway.

Keywords: black carbon, aerosols, radiative heating

INTRODUCTION

Aerosols represent a large source of uncertainty in climate modeling, both in terms of estimating their climate impacts and interpreting the nature of the induced changes (Boucher et al., 2013). Here we investigate on the climate response to an hypothetical abrupt increase in black carbon (BC) using a state-of-the-art earth system model, which is a standard approach used to estimate the equilibrium climate sensitivity (ECS) to CO\textsubscript{2}.

Being light-absorbing, BC acts to warm the ambient atmosphere when exposed to solar radiation. This produces a positive radiative forcing and runs counter to the effect of most other anthropogenic aerosols which mostly scatter solar radiation. The swift BC-induced warming of air affects ambient relative humidity and static stability, and in the next instance the cloudiness and cloud water, which is frequently referred to as semidirect effects. Although expected to be minor due to hydrophobic properties, the BC particles can also contribute to indirect aerosol effects which gives an overall negative radiative forcing when aerosol concentrations increase.

Compared to a quadrupling of CO\textsubscript{2}-concentrations, an abrupt amplification of the BC emissions from fossil fuel combustion has a radically different effect on climate. In a recent paper, Sand et al. (2015) increased the BC emissions by a factor 25, making the instantaneous radiative forcing comparable to that attained from the quadrupling of CO\textsubscript{2}. They found that while the radiative forcing was practically the same in both runs, the radiative imbalance due to BC was quickly reduced by 75\% over the course of a year due to rapid feedbacks, while in the CO\textsubscript{2} run a similar reduction required more than 150 years. Sand et al. also showed that the influence of BC on the model climate was much stronger when the model dynamics is coupled to the BC emissions, allowing the BC concentration to adjust to changes in atmospheric circulation and cloud distribution actually induced by the BC-driven forcing.

The model used in Sand et al. (2015) mixed BC too efficiently vertically and the consequence of this artifact has not yet been assessed. In the present study, we will conduct similar experiments as Sand et al., but using a more recent version of the model in which the vertical mixing is more realistic. We will also examine the climate response to more realistic changes in the BC-emissions.

METHODS

The model used is the Norwegian Earth System Model version 1 (NorESM1-M; Bentsen et al. 2013, Iversen et al. 2013). The NorESM is based on the NCAR Community Climate System Model version 4 (Gent et al., 2011), but with a modified atmosphere component and an entirely different ocean model: CAM4-Oslo (Kirkevåg et al., 2013) and a developed version of the Miami Isopycnic Coordinate Ocean Model (MICOM; Bentsen et al. 2013). CAM4-Oslo includes an advanced module for aerosols and aerosol-cloud-radiation interactions (Kirkevåg et al., 2013).
We will perform several sensitivity runs in which the BC-emissions are amplified by a factor 25, following Sand et al. (2015). To assess the importance of the induced changes in the atmospheric circulation on the BC-concentration, we perform two types of BC-runs: emission-driven and concentration driven. In the emission driven run, the BC-concentrations are calculated by the model, allowing changes in the dynamics to alter the concentrations. In the concentration driven run, the BC-concentrations are prescribed from a previous run in which the BC does not influence the dynamics. The difference between the two type runs reveals the importance of letting changes in the atmospheric circulation act back on the BC-concentration.

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References


A new aerosol wet removal scheme for the Lagrangian particle model FLEXPART


1 Department of Applied Environmental Science (ITM), Atmospheric Science Unit, Stockholm University, S 106 91 Stockholm, Sweden
2 Norwegian Institute for Air Research (NILU) PO Box 100 2027 KJELLER
3 Finnish Meteorological Institute (FMI), Air Quality Research, Erik Palmenin aukio 1, P.O.Box 503, FI-00101 Helsinki
4 Division of Atmospheric Sciences, Department of Physics, University of Helsinki, P.O.Box 64 (Gustaf Hallstromin katu 2a) FI-00014 University of Helsinki, Finland

Keywords: FLEXPART, aerosol scavenging, BC, aerosol lifetimes.

ABSTRACT

A new wet removal scheme for aerosols has been implemented in the Lagrangian particle dispersion model FLEXPART (Stohl et al. 2005). The in-cloud nucleation scavenging differentiates between cloud water phases to allow for aerosol and cloud type specific removal. The impaction scavenging scheme implemented for below-cloud scavenging depends on the aerosol size and on the precipitation type and strength. For rain a parameterization by Laakso et al. (2003) was adapted. For snow scavenging, we adopted a parameterization by Kyrö et al. (2009), derived from the same 6 year data from Hyytiala but for the snow events. In-cloud (nucleation) scavenging for particles is an updated version of the scheme by Hertel et al. (1995) with improvements designed to take into account differences in aerosol activation as condensation- and ice-nuclei.

A major update was the added option to read clouds from European Centre For Medium Range Weather Forecasting (ECMWF) meteorological fields, overriding the existing old parameterization. This option gives more frequent below-cloud scavenging below 1000m than the parametrized clouds. Also, higher cloud tops close to equator makes the scheme overall have slightly more frequent in-cloud events, and a much more realistic cloud distribution than the parameterization. The frequency of below-cloud events was 13% of all wet removal events, and so in-cloud dominate the wet removal.

Sensitivity tests were conducted for three distinctly different aerosols. Highly soluble $^{137}$Cs attached mainly to sulfate aerosol, black carbon (BC) and mineral dust, all posing different challenges in terms of solubility, volatility and wet removal. Based on Fukushima nuclear power plant accident emissions of $^{137}$Cs, direct comparison between FLEXPART model lifetime and observation based estimates are very close, using an realistic aerosol size distribution. Total model aerosol e-folding times were 10.3 days against the estimated 14.2 days for an unbiased concentration estimate.

Modeled BC were compared to atmospheric concentrations (Fig.1). FLEXPART concentrations (blue) and observed (black) compare well over a range of stations from close to emissions (Melpitz) to remote stations in the Arctic, with $r^2 = 0.47 - 0.79$ at the different stations for 6 hourly observations. Also for mineral dust realistic atmospheric concentrations were obtained.

ACKNOWLEDGEMENTS

This work was supported by NordForsk as part of the Nordic Centre of Excellence Cryosphere Atmosphere Interactions in an Arctic Changing Climate (CRAICC).
Figur 1: Monthly statistics of 6hr average station concentrations for 2007, modeled and observed BC concentrations at 6 different stations. The black boxes cover the 25-75% percentile range, the black horizontal line the median, and the black whiskers the 10-90% percentile range of the observations. Modeled median values are plotted in blue with vertical lines showing the 25-75% percentile range. The stippled blue line shows the model mean.

REFERENCES


Laakso, L., Gronholm, T., Rannik, U., Kosmale, M., Fiedler, V. and co-authors : Ultrafine particle scavenging coefficients calculated from 6 years field measurements Atm. Env. 37, doi:10.1007/s11270-005-9018-


SECONDARY ORGANIC AEROSOLS AT NORTHERN LATITUDES – INFORMATION FROM MOLECULAR TRACER ANALYSES OBTAINED DURING CRAICC

A.M.K. HANSEN¹, K. KRISTENSEN¹ and M. GLASIUS¹

¹Department of Chemistry, iNANO and Department of Arctic Research, Aarhus University, Denmark.

Keywords: SOA, ORGANOSULFATES, CARBOXYLIC ACIDS, AEROSOL PROCESSES.

INTRODUCTION

Secondary organic aerosols (SOA) in the atmosphere contribute to particle growth and SOA levels and chemical composition affect aerosol climate effects and properties. In this work we have used molecular tracer analysis to investigate sources and processes contributing to SOA at northern latitudes including the Arctic. Specifically we have investigated carboxylic acids to trace both biogenic and anthropogenic SOA as well as organosulfates (OS). OS are formed through heterogeneous reactions involving organic gasphase precursors (from either biogenic or anthropogenic sources) and oxidized sulfur compounds, primarily originating from anthropogenic sources (Glasius and Goldstein, 2016). The presentation will give an overview of results obtained during CRAICC on formation and occurrence of SOA, as well as climate effects of OS.

METHODS

Aerosol samples were collected on filters using both a high-volume sampler and a low-volume sampler equipped with a denuder for collection of organic gases. Chemical analyses of aerosols focused on analysis of carboxylic acids and organosulfates of anthropogenic and biogenic origin using ultrahigh-performance liquid chromatography coupled to quadrupole time-of-flight mass spectrometry (UHPLC-QTOF-MS) as described by Kristensen and Glasius (2011). The results were compared with supporting measurements including organic mass and inorganic ions in aerosols obtained by aerosol mass spectrometry and ion chromatography.

CONCLUSIONS

Levels and composition of SOA vary considerably between sites, depending on local sources and formation, as well as long-range transport (Hansen et al., 2016; Kristensen et al., 2016, Nguyen et al., 2014). One interesting example is the transport of air masses from Hyytiälä in Finland to Vavilhill, Sweden, where SOA levels general decline due to dilution, and some compounds seem furthermore to degrade during transport (Fig. 1). More details will be given in the presentation.

Formation of OS may influence properties such as surface tension of aerosol particles (Hansen et al., 2015), which should be investigated further with more species of OS. The effect on the hygroscopicity parameter κ was low for OS derived from limonene.
Figure 1. a) Concentrations (ng µg⁻¹) of SOA tracers normalized to organic matter in Hyytiälä the night between May 22nd and 23rd and in Vavihill the night between May 25th and 26th. NOS are nitrooxy organosulfates. OS are organosulfates of monoterpenes (M), PAH, isoprene (I), and isoprene or anthropogenic precursors (I/A). Carboxylic acids are 1. generation (1GM) and 2. generation (2GM) biogenic acids, fatty acid derived (FD) or derived from anthropogenic precursors (A).
b) A cluster of air mass trajectories arriving at Vavihill the night between May 25th and 26th - the yellow star shows the location of Vavihill and the green star Hyytiälä. (Hansen et al., 2016).

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REFERENCES

MARINE ORGANIC AEROSOLS AS EFFECTIVE ICE NUCLEI AT HIGH LATITUDES?

M. HUMMEL¹ and J.E. KRISTJANSSON¹

¹Section for Meteorology and Oceanography, Department of Geosciences, University of Oslo, Oslo, Norway.

Keywords: Aerosol-Cloud-Interaction, Atmospheric ice nucleation, Ocean-Atmosphere-Interaction.

INTRODUCTION

Ice particle concentrations are a key parameter for cold clouds, exerting a strong influence on cloud lifetime, precipitation release, and the cloud radiative effect. The availability of ice-nucleating particles (INPs) and the temperature range in which they become activated determine the rate of ice formation in clouds (Hoose und Möhler, 2012). Particles from marine sources may contribute to ice formation in clouds, as they are abundant in the atmosphere and some of them have been found to be ice-nucleating active, but the extent of their influence on clouds is not known (Wilson et al., 2015).

Wilson et al. (2015) collected marine INPs from the sea surface microlayer and analysed their ice nucleation efficiency with a cold stage. It showed that marine INPs nucleate ice at higher temperatures than subsurface water and thus can contribute to heterogeneous freezing in mixed-phase clouds. Even in cirrus clouds, marine INPs may play a role, as their ice nucleation surface site density as a function of RHₖᵢₑ at -40°C has been shown to be larger than for mineral dusts (ATD, kaolinite, and feldspar).

METHODS

In this study, we test the influence of marine organic aerosols on clouds via immersion freezing with the earth system model NorESM (Norwegian Earth System Model; Bentsen et al., 2013). The model is based on the Community Earth System Model (CESM1.2) and its atmospheric part (CAM5 Oslo) is based on the Community Atmosphere Model (CAM5.3). Marine organic aerosols are part of the sea spray aerosol and are ejected during bubble bursting. INPs are associated with exudates or other macromolecules mainly from diatoms. Hence, their concentration is related to the sea salt aerosols in the model simulation. Two parameterizations for ice nucleation of marine INPs are tested. A fit from Wilson et al. (2015) is expressed as an exponential function of temperature multiplied by the total organic content. In addition, measurement data from Wilson et al. (2015) is used to determine contact angle and activation energy to calculate heterogeneous freezing according to classical nucleation theory.

CONCLUSIONS

Our first results indicate that high marine INP concentrations at around 700 hPa occur at high latitudes (Figure 1). At this height, the ambient temperature at high latitudes between -20°C and -10°C is favourable for marine INPs to nucleate ice. These regions also have low mineral dust concentrations, which might increase the influence of marine INPs on clouds. However, regions with high marine INP concentrations do not match with model simulations in Wilson et al. (2015) with the global aerosol process model (GLOMAP), but are shifted further polewards. In the NorESM simulation, ice nuclei concentrations from marine organic aerosols strongly depend on temperature and do not necessarily coincide with large sea spray concentrations. At mid-latitudes, marine INP concentrations rank below dust INP by at least one order of magnitude.

Further, this presentation will describe the influence of marine INP on cloud properties and give an estimate of the cloud radiative effect of marine INP.
Figure 1. Annual mean cloud-borne marine organic aerosol concentration per cm$^3$ at ~700 hPa (coloured) and Temperature at the same level in °C (contoured).

REFERENCES


Study on chemistry of arctic haze in north of Greenland

H. JUNNINEN¹, N. SARNELA¹, L. AHONEN¹, T. JOKINEN¹, J. MIKKILÄ¹, O. PERÄKYLÄ¹, D. WIMMER³, T. PETAJÄ, H. SKOV²,³, I. E. NIELSEN², M. KULMALA¹ AND M. SIPILÄ¹

¹Department of Physics, University of Helsinki, Finland.
²Department of Environmental Science, Aarhus University, Roskilde, Denmark.
³University of Southern Denmark, Institute of Chemical Engineering and Biotechnology and Environmental Technology, Odense, Denmark.

INTRODUCTION
New particle formation is a process where molecular clusters form from atmospheric vapours by condensation and later the clusters can grow into larger particle sizes and act as cloud condensation nuclei. New measurement techniques have enabled studying even the first steps of new particle formation. In previous studies sulphuric acid (Sipilä et al., 2010) and oxidized organic compounds (Ehn et al., 2014) have been seen to be responsible of new particle formation. Until recent years the composition of newly formed particles has not been studied in the Arctic. Since there is little if any vegetation in the Polar Regions the organics are not likely to play a significant role in particle formation. Instead there has been observed iodine during new particle formation events (Allan et al., 2015).

We conducted a measurement campaign in the Arctic having three major objectives: 1) getting more insight into new particle formation and nucleation processes in the Arctic, 2) trying to characterize Arctic haze and 3) indentifying and characterizing the changes in atmospheric chemistry from dark to sunlight period.

MEASUREMENT CAMPAIGN AND INSTRUMENTATION
We conducted an intensive measurement campaign in the framework of Nordic Center of Excellence “Cryosphere atmospheric Interaction in a Changing Climate (CRAICC)” at Villum Research Station in Northern Greenland (81º 36’N 16º39’W, Fig. 1). The Villum Research Station is located on the small peninsula Prinsesse Ingeborgs Halvø in the vicinity of Station Nord military camp. The Research Station was opened in 2015 including an Atmospheric Observatory located about 2 km from the military camp. The campaign started in mid-February 2015 and was going on until the end of August 2015.

The Villum research station has continuous measurements of meteorological parameters and ozone concentration. Also gaseous elemental mercury, black carbon and filter pack measurements have been conducted there during the last ten years. Particle size distribution of 10 – 900 nm has been measured with Scanning Mobility Particle Sizer (SMPS, Wang and Flagan, 1990) since 2010. During the CRAICC measurement campaign we used several mass spectrometers, particle spectrometers and particle counters in addition of the continuous measurements to study vapour and particle concentrations and the new particle formation on the site.

We had nitrate-Cl-API-TOF (Chemical Ionization Atmospheric Pressure interface Time-Of-Flight mass spectrometer, Jokinen et al., 2012) to measure extremely low volatility vapours such as sulphuric acid and molecular clusters. We used acetate-Cl-API-TOF (Bertram et al., 2011) to measure low volatility vapours such as formic acid. Ambient ions were measured with API-TOF (Junninen et al., 2010). Particle concentrations of 0.8 – 40 nm particles were measured with Air Ion Spectrometer (AIS, Mirme and Mirme, 2013), sub-3 nm particles were measured with Particle Size Magnifier (PSM, Vanhanen et al., 2010) and the particle composition was measured with an Aerosol Mass Spectrometer (Canagaratna et al., 2007). Inlet camera was used to take photo of sampling scene every minute (Raspberry Pi with camera module).
PRELIMINARY RESULTS

Earlier studies have been treating an arctic haze as long lasting phenomenon peaking during springtime. But not all the time during the spring the visibility is reduced and arctic haze is present. We took approach where we developed a method to separate the arctic haze events from non-haze periods. We used several criteria to identify the haze events: 1) during an haze event the small air ions are absorbed by haze and large 30-40nm ions are visible. 2) wind speed has to be low, in order to separate from snow storm 3) temperature has to be freezing in order to separate from fog and 4) visibility had to be clearly reduced, this was identified by calculating contrast (range between darkest and lightest pixel) of each photo. Figure 1 illustrates visibility conditions before and during a haze event.

Figure 1. An arctic haze event on 9 May 2015, left image was taken on 16:30 and right image 19:08. Clear reduction in visibility is visible.

The data analysis is still in progress and we are going to further examine these results. After identifying all haze events we are looking at the frequency of the events and examining the air mass origin by air mass back trajectories. Further we will observe the changes in air composition from nitrate and acetate CI-APiTOF and also aerosol composition changes using AMS.

REFERENCES


JOINT CRAICC-PEEX RESEARCH AND EDUCATION ACTIVITY
MAIN RESULTS OF SERIES OF JOINT WORKSHOPS ORGANIZED IN 2015-2016

H.K.LAPPALAINEN1,2, T.PETÄJÄ1, A. MAHURA3, A.BAKLANOV4, J.BÄCK1, L.KULMALA5, T.LAURILA2, I.ESAU6, L.BOBYLEV1,6, T.VESALA1, S. ZILITIKEVICH7 and M.KULMALA1

1Dept. of Physics, P.O. Box 64, FI-00014 University of Helsinki, Finland.
2Finnish Meteorological Institute, P.O. Box 503, FI-00101 Helsinki, Finland
3Danish Meteorological Institute, Research and Development Department, 2100, Copenhagen
4 World Meteorological Organization, 1211 Genève, Switzerland
5 Department of Forest Sciences, University of Helsinki, 00014 Helsinki, Finland
6Nansen Environmental and Remote Sensing Center/Bjerknes Centre for Climate Research, 5006 Bergen, Norway
7Nansen International Environmental and Remote Sensing Center, St. Petersburg, Russia

Keywords: short-lived climate forcers, Arctic shipping, carbon exchange, changing Arctic, permafrost

INTRODUCTION

In 2014 Nordforsk opened a call for a joint research and education activity enhancing collaboration between Nordic Centres of Excellence and Russia research communities. A joint proposal introduced by Nordic Center of Excellence “Cryosphere-atmosphere interactions in a changing Arctic climate” (CRAICC) and Pan-Eurasian Experiment (PEEX) was selected for funding for the years 2014-2016. The aim of this activity was to enhance research collaboration between CRAICC and PEEX in six selected topical fields: (i) short-lived climate forcers in the Arctic and Eurasia, (ii) carbon exchange in the soil/cryosphere – vegetation - atmosphere continuum, (iii) climate change for Arctic seas and shipping, (iv) climatology of the high-latitude planetary boundary layer and (vi) climatology of the high-latitude planetary boundary layer and turbulent exchange across strongly heterogeneous interface.

The joint CRAICC-PEEX activity was implemented via organizing series of workshops representing in a frame of above listed topical areas in 2014-2016. The Nordic partners representing CRAICC have been University of Helsinki, Finnish Meteorological Institute, Norwegian Institute for Air Research, Stockholm University, University of Århus, University of Iceland, and the partners representing PEEX and Russian communities have been Nansen Environmental and Remote Sensing Center, Danish Meteorological Institute, Institute of Geography (RAS), Moscow State University, AEROCOSMOS, Institute of Atmospheric Optics (SB RAS), Russian State Hydrometeorological University, Institute of Geography (IG RAS) and Laboratory of Climatology (IG, RAS).

WORKSHOP OVERVIEW

The 1st CRAICC-PEEX workshop brought together 17 participants from Russia, Sweden, UK and Finland for topical sessions on the SLFC-modelling-in situ observations in the Arctic and subarctic regions of Eurasia. The WS was organized by the University of Helsinki in a connection of UHEL-UK modelling WS and Helsinki University summer school in Hyytiälä, Finland. The WS-1 process, discussions were continued in a connection of the 1st PEEX Science Conference in Helsinki in February 2015. During this process we have updated the PEEX – CRAICC communities with on-going preparatory work for the hierarchial PEEX observation network. Starting from August 2014 we have made preparatory work for metadata collection of the exiting land- atmosphere observation activities and networks in Russia, China and in the Nordic Countries. The meta database is an interactive tool that will be updated regularly by the PEEX community and station operators. Also the pathways to solidify the PEEX network have been analyzed including how to connect the existing stations the meta database and actions to connect individual activities to GAW station network. The results of a case study on evaluating model simulated
short lived climate pollutants in the high latitude Pan-Eurasian region” (Spracklen et al.) will be submitted to J. Atmospheric Chemistry and Physics PEEX Special issue.

The 2nd joint workshop on the carbon exchange research and the ecosystem research infrastructures in the Arctic and subarctic regions of Eurasia was organized together by the University of Helsinki and Finnish Meteorological Institute and took place in February 2015 in Helsinki Vuosaari, Finland. The workshop brought together 43 participants from Russia, Sweden, Germany and Finland. The WS was aimed to explore and enhance the collaboration possibilities among participants and to design the PEEX observation infrastructure in carbon exchange research. The scientific focus was on the issues how to measure the key processes and feedbacks, key regions and interactions between measurements and models. The workshop managed to bring in a large selection of infrastructures and research themes, linking the different carbon cycle processes together. Understanding of these processes in the Arctic is still limited, and many regions are lacking proper facilities to conduct comprehensive measurements. An important topic was how to improve the joint work of the community in making better use of the existing measurements and data. It was agreed that the data flow should be improved, but that currently there are great obstacles to obtain data from Russia. The coverage of data for models was also discussed. The GHG fluxes are rather small compared to anthropogenic emissions, and thus it seems that the potential misrepresentation or lack of measurements does not largely affect the outcomes of GCMs. The largest uncertainties are in wetland emissions, energy exchange, snow cover changes, albedo, and these measurements should be improved.

The 3rd joint workshop for “Climate Change for Arctic Seas and Shipping” took place in Aug 2015 at Danish Meteorological Institute (DMI, Copenhagen, Denmark). In total, more than 30 researchers and students attended the event from universities and research institutions from China, Denmark, Finland, Japan, Russia, Switzerland, and Sweden (http://research.dmi.dk/events/upcoming-events/3rd-craicc-peex-workshop). Based on 3rd WShop outcomes, it is critical to follow what kind of needs and requirements are important to take into account for maritime industry, services and increased shipping in the Arctic, where providing ice and maritime services and predicting capabilities for shipping are essential. Climate change projections became important for possibilities to increase ship traffic in the Arctic region. Future scenarios of increased ship emissions, effects on atmospheric pollution, feedbacks on meteorology and climate are also valuable to investigate. Forecasting of extreme weather events for shipping in this region and link with climate change became very important. Moreover, requirements from end-users on what is needed for practical realization and mitigation scenarios should be realised.

The 4th workshop on “Estimating and monitoring anthropogenic emission in the Arctic by using remote sensing, was organized together with GC Rieber Climate Institute (GCR) and Pan-Eurasian Experiment (PEEX) workshop at NERSC, Norway in September 2015. The Climate Processes Group – GC Rieber Climate Institute (GCR) at the Nansen Environmental and Remote Sensing Centre is developing a coherent research strategy to address the scientific challenges of the rapidly warming high latitudes of the Earth. This workshop summarized the available expertise in the GCR and drafted ideas for perspective research directions compatible with the international Pan-Eurasian Experiment (PEEX) (Lappalainen et al., 2015). PEEX (https://www.atm.helsinki.fi/peex/) is a multidisciplinary, multi-scale bottom-up open scientific initiative. The PEEX approach emphasizes that solving challenges related to climate change, air quality and cryospheric change requires largescale coordinated co-operation of the international research communities. The workshop presentations discussed both the large- and small-scale components of the climatology of the high-latitudes. A particular attention has been given to the links between climate scales as well as to the scales shaping the climate impact on society (Esau and Petterson 2016).

The 5th and 6th workshops on “the climatology of the high-latitude planetary boundary layer” and “the turbulent exchange across strongly heterogeneous interface” will be organized in May 2016, in Beijing China as a part of the 2nd PEEX Science Conference.

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REFERENCES


AIRBORNE MEASUREMENTS OF SMALL CLUSTERS AND AIR IONS
K. LEINO1, R. VÄÄNÄNEN1, J. LAMPLAHTI1, A. MANNINEN1, T. MATILAINEN1, H. LAAKSO1, J. LEVULA1, H.E. MANNINEN1, T. PETÄJÄ1, and M. KULMALA1

1Division of Atmospheric Sciences, Department of Physics, University of Helsinki, Finland.

Keywords: AIRBORNE OBSERVATIONS, AEROSOLS, ATMOSPHERIC CLUSTERS, NEW PARTICLE FORMATION.

INTRODUCTION

Airborne observations of atmospheric aerosols have been performed in the lower troposphere during several campaigns between 2009 and 2015. The measurements have focused on studying the new particle formation (NPF) events. NPF is a frequent phenomenon and a major source of climatically relevant aerosol particles in the atmosphere (e.g. Kulmala et al., 2013). The open question is where, when and how the new particle formation occurs in the atmosphere. Recently the atmospheric small ions have proved to be a suitable indicator for NPF events (Leino et al. 2016) at ground level. Under investigation is the contribution of air ions to new particle formation in other altitudes of the lower atmosphere.

METHODS

Airborne aerosol measurements over the boreal environment have been performed close to Hyytiälä SMEAR II field station, in southern Finland (61°51’N, 24°17’E). Flights were operated from Tampere-Pirkkala airport. A light airplane, Cessna FR172F, was used as a platform. The measurement setups included several combinations of different aerosol instruments. The total particle number concentration was measured with the ultrafine Condensation Particle Counter (uCPC, cut-off size of 3 nm), and with Particle Size Magnifier (PSM, cut-off size of 1.5 nm). The particle size distribution in size range of 10–400 nm was measured with Scanning Mobility Particle Sizer (SMPS) and in the size range of 1.7–40 nm with Neutral Cluster and Air Ion Spectrometer (NAIS). The NAIS measures also the size distribution of naturally charged particles in size range of 0.8–40 nm.

PRELIMINARY RESULTS

During the NPF events observed at Hyytiälä, the particle formation was also observed by airborne measurements. We assessed that then nucleation and particle growth took place inside the mixed planetary boundary layer (PBL) and new particle formation events could occur throughout the boundary layer (Schobesberger et al. 2012, Väänänen et al, in preparation). Addition to the PBL nucleation, we observed sub-10-nm particles growing in the free troposphere at altitudes between 1800 and 3800 m a.s.l. (Väänänen et al, in preparation).

Our observations also suggest that NPF could be enhanced in locally limited regions of the PBL. Analysis of these regions together with wind and radar data suggests that NPF increases along large helical circulations in the PBL, known as roll vortices (e.g. Etling and Brown, 1998). The parallel convective bands of small sub-10-nm aerosol particles caused by rolls were observed. Those bands occurred roughly in 40 % of the days when NPF was observed.

We used the NAIS to measure airborne ions in September, 2014. A band of small cluster ions (0.8–1.5 nm) was visible at all altitudes between 300–2500 m a.s.l. The Aitken mode (20–100 nm) background particles measured with NAIS were observed to be quite homogenous inside the boundary layer.

Sub-3-nm neutral particles were studied with the PSM A10 during summer and autumn 2015 campaigns. As an example case, Fig. 1 shows the vertical profiles of number concentrations of particles with sizes of >1.5
nm (PSM), >3 nm (uCPC) and 10–400 nm (SMPS). The sub-3-nm particles were observed throughout the PBL.

CONCLUSIONS

The vertical and horizontal extension of NPF inside the lower troposphere was studied using a light aircraft as a platform. In addition with measurements of air ions we can assess what is the contribution of charged clusters, and ion-induced particle formation as a function of altitude.

![Particle total concentrations](image)

Figure 1. Vertical distribution of total particles measured with three instruments during measurement flight on 24.8.2015 at 9:15-11:30 UTC+2.

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REFERENCES

Väänänen, R. et al. (2016) in Preparation.
INTERACTIVE MARINE AEROSOL EMISSIONS AND CLOUD MICROPHYSICS BUDGETS IN NORESM: PRELIMINARY RESULTS FROM THE DEVELOPMENT PHASE OF NORESM2

A. LEWINSCHAL1, A. GRINI2, T. IVERSEN2 and Ø. SELAND2

1 Department of Meteorology, Stockholm University, Stockholm, Sweden.
2 Norwegian Meteorological Institute, Oslo, Norway.

Keywords: NorESM, Sea spray, DMS, Cloud microphysics.

INTRODUCTION

The second version of the Norwegian Earth System Model (NorESM2) is currently under development. NorESM is largely based on the Community Earth System Model, but uses an alternative aerosol module and a modified version of the Miami Isopycnic Coordinate Ocean Model to represent the ocean. Among the changes in NorESM2, compared to the previous version, is an update of the atmospheric host model from version 4 of the Community Atmospheric Model (CAM4) to version 5 (CAM5). With this change of the atmospheric model, many of the atmospheric physics schemes are changed. In addition to the change of the atmospheric model, NorESM-specific parts of the models have been updated. Here, some of these updates are presented along with preliminary results from the development phase.

INTERACTIVE MARINE AEROSOL AND AEROSOL PRECURSOR EMISSIONS

For NorESM2, interactive emissions of marine dimethyl sulphide (DMS) and particulate organic matter (POM) have been introduced. In NorESM1, prescribed DMS emission fields from the Aerocom project (Dentener et al., 2006) are used. For POM in NorESM1, the emission source is a uniform scaling to the sea salt mass emissions to match the estimate of the global POM emissions by Spracklen et al. (2008) of 7.7 Tg/yr.

The parameterisation that has been introduced for DMS emissions in NorESM2 is that of Nightingale et al. (2000). With this parameterisation the emissions become wind speed dependent. However, climatological fields for the surface water DMS concentrations are necessary to calculate the emissions in the model. In addition to this parameterisation of DMS emissions, DMS surface fluxes from the ocean model into the atmospheric part are now supported. Thus, with the inclusion of the ocean bio-geochemical module HAMburg Ocean Carbon Cycle (HAMOCC), fully interactive DMS emissions based on prognostic DMS ocean concentrations can be simulated.

For marine POM emissions, the parameterisation developed by O’Dowd et al. (2008) and updated by Vignati et al. (2010) have been implemented. The parameterisation estimates the organic fraction of the total sea spray aerosol emissions. In NorESM2, the inorganic part of the sea spray emissions are wind driven and temperature dependent. Similarly to the DMS emission parameterisation, the marine POM emission parameterisation relies on a climatology of sea surface concentration of the emission constituent. For marine POM, the sea surface chlorophyll concentrations climatology is used.

The emissions of both these natural aerosol and aerosol precursor increase with the newly introduced parameterisations compared to the formulation for the emissions in NorESM1. The annual DMS
emissions increase by 75% and the marine POM emissions increase by 160%. Despite this increase, the magnitude of the emissions are still within the estimated ranges for both DMS and marine POM, which, however, are associated with large uncertainties.

CLOUD MICROPHYSICS BUDGETS

In CAM5 the cloud microphysics scheme has been updated to the double-moment scheme of Morrison and Gettelman (2008). As part of the evaluation work and preparation for the tuning of NorESM2, the tendency budgets for both mixing ratio and number concentration for liquid water and ice have been analysed. In this initial investigation it was found that one of the largest sinks for both liquid water droplet and ice crystal number concentrations is a droplet and crystal size distribution adjustment that compensates for microphysical processes that are not explicitly described for in the microphysics scheme.

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REFERENCES


QUANTIFYING EARTH SYSTEM FEEDBACKS WITH NORESM-CRAICC EARTH SYSTEM MODEL

R. MAKKONEN¹, J.E. KRISTJÁNSSON², Ø. SELAND³, A. KIRKEVÅG³, T. IVERSEN³, I. RIIPINEN⁴, J.C. ACOSTA NAVARRO⁴, H. STRUTHERS⁵, M. SAND⁶ and M. KULMALA¹

¹Department of Physics, University of Helsinki, Finland
²Department of Geosciences, University of Oslo, Norway
³Norwegian Meteorological Institute, Oslo, Norway
⁴Department of Environmental Science and Analytical Chemistry, Stockholm University, Sweden
⁵National Supercomputer Center, Linköping University, Sweden
⁶Center for International Climate and Energy Research, Oslo, Norway

Keywords: ESM, CLIMATE, FEEDBACKS

DEVELOPMENT OF NORESM-CRAICC

The developments in CRAICC have led to a new version of an Earth System Model, namely NorESM-CRAICC. This model adaptation gathers the expertise and knowledge generated by the project throughout several Earth System components, implementing new parameterizations to the Norwegian Earth System Model (Bentsen et al., 2013). The NorESM-CRAICC includes developments on e.g. nucleation of atmospheric aerosols (Makkonen et al., 2014), formation of secondary organic aerosol (Makkonen et al., 2014), new sea-spray emission parameterization (Salter et al., 2015), and interactive oceanic DMS emission. The NorESM-CRAICC has been extensively evaluated, e.g. against atmospheric aerosol observations (Makkonen et al., 2014). The development and application of NorESM-CRAICC continues in several post-CRAICC activities.

APPLICATION TO EARTH SYSTEM FEEDBACKS

The main driver behind NorESM-CRAICC development has been in improved quantification of Earth System feedbacks, especially those acting via high-latitude mechanisms. While traditional feedbacks behind Arctic amplification have been previously assessed to great detail, the work in CRAICC focused on several poorly-quantified feedback mechanisms. Specifically, the CRAICC research has focused on

1) High-latitude warming resulting in increased BVOC emissions and aerosol formation
2) Reduction of sea ice and resulting changes in marine emissions
3) The impact of short-lived climate forcers on the Arctic climate
4) Connection of European emissions to Arctic change
5) Change in aerosol and precursor emissions due to land-use change

CRAICC has contributed to several assessments of the above interactions with Earth System modeling. Struthers et al. (2013) quantified climate-induced changes in sea salt emissions during 1870-2100. Their study indicated that during the whole period, emission of coarse mode sea salt particles increased by 10% contributing to overall radiative budget over marine regions. Acosta Navarro et al. (2016) studied the linkages between European aerosol emissions and Arctic warming. They found that the strong decrease in European emissions since 1980 has had a significant impact on Arctic energy budget. Sand et al. (2015) carried out extensive set of simulations to study the contributions to Arctic temperature change due to emissions from different sectors, regions and pollution components. NorESM-CRAICC has been applied to study the potential Earth system feedback mechanism acting via biogenic VOC emissions (BVOC), secondary organic aerosol (SOA) formation, and resulting direct and indirect effects of aerosols on climate. We will present an outline of past and ongoing developments of NorESM-CRAICC, together with an overview of the applications of the model to meet CRAICC objectives.
ACKNOWLEDGEMENTS

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REFERENCES

CRYOSPHERE AND BC, OC AND ICELANDIC VOLCANIC ASH AND DUST - IMPACTS ON SNOW ALBEDO, DENSITY AND MELT

O. MEINANDER1, P. DAGSSON-WALDHAUSEROVA2,3,4,5, M. DRAGOSICS3, J. SVENSSON1, A. VIRKKULA1, J. PELTONIEMI6, A. KONTU7, O. ARNALDS2, H.-R. HANNULA7, N. KIVEKÄS1, H. LIHAVAINEN1, M. GRITSEVICH8, A.N. ARSLAN1, M. LEPPÄRANTA6, and G. DE LEEUW1,6

1Finnish Meteorological Institute (FMI), Helsinki, Finland
2Agricultural University of Iceland, Faculty of Environmental Sciences, Hvanneyri, Iceland
3University of Iceland, Institute of Earth Sciences, Reykjavik, Iceland
4Czech University of Life Sciences Prague, Faculty of Environmental Sciences, Prague, Czech Republic
5University of Iceland, Faculty of Physical Sciences, Reykjavik, Iceland
6University of Helsinki, Department of Physics, Helsinki, Finland
7Arctic Research Center, Finnish Meteorological Institute, Sodankylä, Finland
8Finnish Geospatial Research Institute, Masala, Finland

Keywords: ARCTIC, CRYOSPHERE, DUST, BLACK CARBON, ORGANIC CARBON, SNOW MELT, DENSITY, ALBEDO.

INTRODUCTION

Snow surface reflectance and albedo depend on snow properties as well as environmental conditions; e.g. on impurities deposited on the snow (e.g., Warren and Wiscombe, 1980). Within the NCoE CRAICC (Cryosphere-Atmosphere Interactions in a changing Arctic Climate, http://www.atm.helsinki.fi/craicc/), our snow reflectance and albedo related activities include: a) long-term UV albedo measurements on Arctic seasonal snow at Sodankylä, North-Finland, combined with weekly analysis of EC/OC in snow, as well as Antarctic surface UV albedo measurements at Marambio, Antarctic Peninsula; b) experimental field campaign measurements on snow and ice melt, density and albedo and reflectance changes at 320-2500 nm, induced by artificial deposition of soot, volcanic sand and glaciogenic silt. The CRAICC is, together with NCoE DEFROST (“Depicting northern wetland feedbacks in the climate system as affected by permafrost, snow and ice”) and NCoE SVALI (“Stability and Variations of Arctic Land Ice”), within the Top-level Research Initiative (TRI) sub-programme “Interaction between Climate Change and the Cryosphere” (ICCC). This TRI is the largest joint Nordic research and innovation initiative to date, aiming to strengthen research and innovation regarding climate change issues in the Nordic Region. The CRAICC is coordinated through the University of Helsinki, and lead by Prof. Markku Kulmala. The CRAICC work is divided into eight work packages. The work of this paper is mainly within the WP2 “Cryospheric changes”. The CRAICC also includes Fellowship projects.

MATERIALS AND METHODS

Here we summarize our research work on Cryospheric changes, carried out within the Nordic Centre of Excellency (NCoE) project “Cryosphere-atmosphere interactions in a changing Arctic climate” (CRAICC, 2011-2016). The in situ data were mainly collected in Arctic Sodankylä and Antarctic Marambio GAW stations (Meinander et al. 2016, under review for GI), and during experiments in Sodankylä and Kumpula, Helsinki, and Iceland. Since 2007, the local UV albedo of snow at the Sodankylä Arctic Research Centre (67°22′N, 26°39′E, 179 m asl), Finland, is measured at the operational albedo field. The Arctic UV albedo measurements were planned and initiated as part of the International Polar Year IPY-2007 activities (IPY project ORACLE-O3) (Meinander et al., ACP, 2008). Two sensors of UV Biometer Model 501 from Solar Light Co. (SL501) with similar spectral and cosine responses are used, one facing upwards and one downwards, at a height of 2 m. The SL501 spectral response resembles the action spectrum for erythema,
wavelengths in the UVB (280–310 nm) are most weighted. The albedo of snow (A) is the ratio of the up-welling UV irradiance to the down-welling irradiance (A = UVery↑/UVery↓), at 2\pi angle

Our Soot on the Snow (SoS-2013) experiment (Meinander et al. 2014, Peltoniemi et al. 2015, Svensson et al. 2016) was carried out in Sodankylä (67°22’N, 26°39’E, 179 m a.s.l.), Finland, North of the Arctic Circle, to study the effects of deposition of BC, Icelandic volcanic sand and glaciogenic silt on the surface albedo, snow properties and melt of the seasonal snow. The BC was soot originating from chimneys above residential wood-burning fireplaces, except for one experimental spot with soot from an chimney of an oil burner, and another one with soot from a peat-burning power plant. The volcanic sand was a dark mixture of the volcanic ash of glaciofluvial nature, originating from under the Myrdalsjokull glacier, which may be mixed with the ash of the Eyjafjallajokull eruption in 2010 and the Grimsvotn eruption in 2011. The glaciogenic silt was lighter in colour than sand, from light-brown to slightly yellowish colour consisting mainly of silt and some coarse clay sized particles, which could be deposited on the local glaciers as well as transported over several hundreds of kilometers towards Europe.

The CRAICC Fellowship project of Phil.Lic. Outi Meinander, Finnish Meteorological Institute (CRAICC Fellow from 1.October 2015 to 30. June 2016) is with the title “Icelandic Volcanic Ash and Dust: Impacts on Snow Albedo, Density and Melt.” Partners of the project are Finnish Meteorological Institute, Climate Research, and Institute of Earth Sciences, University of Iceland. The project aims at gaining new information as follows: “Climatic effects of the deposition of light-absorbing particles on snow have been proposed to result from reduced snow albedo and increased melt. Such effects are usually linked to soot (BC), but also volcanic ash and dust from Iceland have an influence which may be larger in the Arctic region than that of soot. There are over 30 active volcanoes or volcanic systems in Iceland, and seven major dust sources. The properties of ash and dust from these sources show considerable physical and chemical variability. The main objective of the project is to study the influence of the deposition of volcanic ash and dust on snow properties (albedo, density and melt), and compare these to soot (BC). For the purpose, outdoor and laboratory experiments, together with Icelandic CRAICC members, as well as modeling approaches will be applied. Icelandic ash and dust samples will also be measured at 325-2500 nm with an ASD spectroradiometer coupled to a contact probe.” During this Fellowship period, a short-term scientific visit to Iceland was made in March 2016 (Fig.1). The visit included field work on cryosphere and Icelandic volcanic dust and BC/OC.

Figure 1. Icelandic glacier Solheimarsjokull in March 2016. Snow and ice were sampled from the glacier for further filtering, and filter analysis in the FMI laboratory.

We have published our results in several peer-reviewed papers, where CRAICC has been acknowledged. These include Meinander et al (2013), Meinander et al. (2014), Dagsson-Waldhauserova et al (2015), Peltoniemi et al. (2015), and Dragosics et al. (2016). Most recently, a paper of Meinander et al. (2016) on
Icelandic dust was accepted. Papers under review are by Svensson et al. (2016) for BER and Meinander et al. (2016) for GI, and ms in prep. by Meinander et al. (2016). We have also presented actively our results in international meetings and conferences in Europe and USA. The CRAICC annual meeting abstracts (by Meinander et al.) also provide more detailed results and conclusions (see also Fig 2 here). In the international DUST-2016 conference in Italy, the “Dust and Cryosphere” session will be chaired by Meinander and Dagsson-Waldhauserova in June2016. OM and PD-W will also have own oral presentations after Prof. O. Arnald’s longer talk on Icelandic Dust. The CRAICC work will be continued in future also within the FCoE ATM, COST SNOW ES1404, and the “Pan-Eurasian Experiment” PEEX.

Figure 2. Examples of the methods used in our work. Top panel (from left to right). The Snow density cutter, the Sunset OC/EC Laboratory analyser, snow impurity filters to be analyzed. Lower panel. Sodankylä albedo field. SoS field campaign in Sodankylä. Snow grain size visual detection plate.

CONCLUSIONS

1. BC, OC and albedo

In Meinander et al. (2013), we measured and reported unexpectedly low snow albedo values of Arctic seasonally melting snow in Sodankylä, north of Arctic Circle. Our low albedo results of melting snow were confirmed by three independent data sets. We explained these low values to be due to: (i) large snow grain sizes up to ~3 mm in diameter (seasonally melting snow); (ii) meltwater surrounding the grains and increasing the effective grain size; (iii) absorption caused by impurities in the snow, with concentration of elemental carbon (black carbon) in snow of 87 ppb, and organic carbon 2894 ppb. The high concentrations of carbon were due to air masses originating from the Kola Peninsula, Russia, where mining and refining industries are located. SNICAR-model showed that the impurities absorb irradiance the more the shorter the wavelength.
Figure 3. The SNICAR-model (Flanner et al. 2007) using realistic input parameter values showed that the impurities absorb irradiance the more the shorter the wavelength. The biggest change is at the ultraviolet (UV) (see: Meinander et al. 2013).

2. BC and snow density

In the paper of Meinander et al. (2014), we presented a hypothesis that Black Carbon (BC) may decrease the liquid-water retention capacity of melting snow. We also presented our first data, where both the snow density and elemental carbon content were measured. In our snow density related experiments, artificially added light-absorbing impurities decreased the density of seasonally melting natural snow. No relationship was found in case of natural non-melting snow.

Figure 4. The density of melting snow (b) suggested a density decline for snow containing BC. For nonmelting snow (a) this was not obvious (Figure adapted from Meinander et al. 2014)
3. Depending on the amount and properties of the particles on snow/ice surface, the impurities can either melt snow or insulate snow from melting (see Dragosics et al. 2015).

Figure 5. Artificially added Icelandic tephra particles (15 g, 85 g and 425 g) on snow increased snow melt compared to control snow. However, the snow with the biggest amount of particles melted slower than the snow with smaller amounts of particles suggesting a possible insulation effect.

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This work was supported by the NCoE CRAICC, FCoE ATM, ATM-DP, Academy of Finland project A4, Maj and Tor Nessling Foundation, and COST-SNOW ES1404 STSM.

REFERENCES
Ground vegetation is a net sink of soil emitted isoprenoids in boreal Scots pine forest

M. Mäki¹, J. Heinonsalo², H. Hellén³ and J. Bäck¹

¹Dept. of Forest Sciences, P.O. Box 27, FI-00014 University of Helsinki, Finland.
²Dept. of Food and Environmental Sciences, P.O. Box 66, FI-00014 University of Helsinki, Finland.
³Finnish Meteorological Institute, P.O. BOX 503, FI-00101 Helsinki, Finland.

Keywords: isoprenoids, boreal soil, microbial activity, mycorrhizal fungi, vegetation, trenching

INTRODUCTION

Boreal soil and ground vegetation emits biogenic volatile organic compounds (BVOCs) from heterogenic soil matric where the interactions between different sources (roots, mycorrhizal fungi and decomposers) are highly complex, leading to strongly varying flux rates. The main monoterpenes sources are suggested to be degrading litter (Aaltonen et al., 2011) and tree roots (Hayward et al., 2001). Mycorrhizal fungi emit isoprenoids (Bäck et al., 2010) and sesquiterpene emission can enhance root surface area (Ditengou et al., 2015). Soil carbon can also act as a sink of isoprenoids (Insam and Seewald, 2010) when decomposers use isoprenoids as a carbon source. Soil enzymes can release substrates for metabolic VOC production (Mancuso et al., 2015), but isoprenoids can inhibit enzyme activity (Adamczyk et al., 2015) soil processes. Trees allocate large proportions (up to 40–73 %) of photosynthesised carbon to belowground (Grayston et al., 1997) and root death can also release carbon to microbes. The aim of this study was to quantify soil isoprenoid fluxes and determine if photosynthesis driven carbon allocation to roots and mycorrhizal fungi affects soil isoprenoid fluxes. Finally, we tested if ground vegetation is a net sink of isoprenoids since isoprenoids stick on plant leaves.

METHODS

Measurements were executed in the southern boreal forest at the SMEAR II (Station for Measuring Ecosystem-Atmosphere Relations) station (61°51’N, 24°17’E). Forest is a 55-yr old Scots pine stand (Pinus sylvestris). Sorbus aucuparia and Picea abies are growing in below-canopy. Soil above a bedrock is Haplic Podzol (soil depth 0.5-0.7 m). The average thickness of the soil horizons is 6.0 cm (O), 2.0 (E) and 16 (B). The ground vegetation includes shrubs (Vaccinium vitis-idaea and V. myrtillus), mosses and grasses. Vegetation cover of vascular and moss species on experimental plots was determined. Measurements were conducted on 3 sites.

Each site includes 20 experimental plots. The experimental plots were trenched by digging around a square volume (0.9 x 0.9 m) of soil until bedrock or up to 50 cm depth and cutting roots between plot and surrounding soil. Soil C input by tree root allocation was controlled by comparing soil, where ingrowth of root and mycorrhizal fungi and microbial mobility was allowed (17 plots) to experimental plot where the ingrowth of tree roots and soil fungi was inhibited by placing isolating mesh (1 µm, 12 plots) around the soil volume or to the treatment where access of decomposers and mycorrhizal fungi was allowed but the ingrowth of tree roots was inhibited (50µm: 6 plots). Both mesh allowed water and nutrients exchange. Ground vegetation allocates part of photosynthetically produced C into the soil and the effect of ground vegetation was studied by comparing soil with vegetation cover (20 plots) to soil where vegetation was removed by cutting (15 plots). Soil water content and soil temperature (depth 0-5 cm) were measured.

Each plot was measured 5-6 times between 15th of April and 23th of October. Isoprenoid concentrations were measured with two steady-state flow-through glass chambers by placing chambers on permanent soil collars. Incoming and outgoing air were sampled (1.5 – 2 h) using sampling flow (0.1 l min⁻¹) into two Tenax TA-Carboback-B adsorbent tubes. Filtered ambient air was continuously pumped (1 l min⁻¹) into the chamber. Chamber volume was flushed for 0.5 hour before sampling to stabilize the system. Hemiterpenes (isoprene and 2-methyl butenol), monoterpenes (α-pinene, camphene, β-pinene, myrcene,
Δ3-carene, p-cymene, limonene and terpinolene) and sesquiterpenes (longicyclene, iso-longifolene, β-caryophyllene, aromadendrene and α-humulene) were measured from tubes. Tubes were analyzed using a thermodesorption instrument connected to a gas-chromatograph and a mass selective detector.

CONCLUSIONS

The most common group of isoprenoids emitted from non-trenched plots were monoterpenes and their total annul flux was 23 µg m⁻² h⁻¹ (Fig 1). Trenching did not affect monoterpene fluxes which could indicate that soil isoprenoid fluxes do not directly depend on presence of the mycorrhizal fungi or roots. Other studies have shown that ground vegetation emits isoprenoids, but in this study, the ground vegetation was a net sink, which was observed as smaller flux from bare soil. Vegetation cover, season and chamber temperature explained 43 % of the monoterpane flux (p<0.05) and season and chamber temperature explained 29 % of the sesquiterpene flux (p<0.01) based on fixed effects linear models. Highest monoterpane fluxes where measured when input of fresh litter increased decomposition activity.

Figure 1. (a) Monoterpene, sesquiterpene and isoprene fluxes and (b) chamber and soil temperatures from non-trenched soil.

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REFERENCES

Physico-chemical properties of Arctic aerosols at Villum Research Station, 
North Greenland

I. E. Nielsen\textsuperscript{1,2}, L. S. Iversen\textsuperscript{2,3,4}, S. B. Svendsen\textsuperscript{1,2}, R. Lange\textsuperscript{1,2}, H. Skov\textsuperscript{1,2}, J. K. Nøjgaard\textsuperscript{1,2}, B. Jensen\textsuperscript{1,2}, A. M. K. Hansen, M. Glasius\textsuperscript{2,3,4}, Q. T. Nguyen\textsuperscript{5} and A. Massling\textsuperscript{1,2}

\textsuperscript{1}Department of Environmental Science, Aarhus University, 4000 Roskilde, Denmark
\textsuperscript{2}Arctic Research Centre, Aarhus University, 8000 Aarhus, Denmark
\textsuperscript{3}Department of Chemistry, Aarhus University, 8000 Aarhus, Denmark
\textsuperscript{4}iNANO Centre, Aarhus University, 8000 Aarhus, Denmark
\textsuperscript{5}Department of Engineering, Aarhus University, 8000 Aarhus, Denmark

Keywords: Arctic aerosols, physico-chemical properties, SP-AMS, SMPS.

INTRODUCTION
Climate change is strongly pronounced in the Arctic. The reasons behind these changes are not well understood while the so-called short-lived climate forcers (SLCFs) as methane, ozone and atmospheric particles are estimated to substantially contribute to the observed warming (Quinn et al., 2008). Climate forcers such as greenhouse gases or atmospheric particles do not have strong sources in the Arctic, as anthropogenic sources are limited in remote areas. However, it is known that atmospheric pollution is transported from other parts of the world during late winter and early spring to Arctic regions. A quantification of the contribution of these pollutants to the observed Arctic warming is still missing.

METHODS
Physico-chemical parameters have been monitored at Villum Research Station (VRS) at Station Nord (SN) in North Greenland (81° 36’ N, 16° 40’ W at 6 m ASL) for many years. Applied techniques comprise the particle number size distribution for particles between 10 and 900 nm using a Scanning Mobility Particle Sizer (SMPS) and the concentration of black carbon using a Multi Angle Absorption Photometer (MAAP). Additionally, inorganic chemical composition was measured with different techniques (IC analysis, ICP-MS analysis) based on weekly filter pack samples. The content of elemental carbon (EC) and organic carbon (OC) has been determined by a thermo-optical method based on high volume samples with weekly time resolution.

Table 1. List of experimental techniques applied and parameters derived at VRS during the CRAICC campaign.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Parameter</th>
<th>Time period / time resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMPS</td>
<td>Particle number size distribution of submicrometer aerosol</td>
<td>Continuously / 5 minutes</td>
</tr>
<tr>
<td>MAAP</td>
<td>Black carbon concentration</td>
<td>Continuously / 30 minutes</td>
</tr>
<tr>
<td>OC/EC analysis of high volume samples</td>
<td>OC/EC concentration of PM10</td>
<td>Several years / 7 days</td>
</tr>
<tr>
<td>IC/ICP-MS of filter pack samples</td>
<td>Concentration of major inorganic ions and elements</td>
<td>Several years / 7 days</td>
</tr>
<tr>
<td>HR-TOF-MS analysis of high volume samples</td>
<td>Inorganic chemical composition of PM10</td>
<td>March – April / 48 hours</td>
</tr>
<tr>
<td>OC/EC analysis of high volume samples</td>
<td>OC/EC concentration of PM10</td>
<td>March – April / 48 hours</td>
</tr>
<tr>
<td>SP-AMS</td>
<td>Chemical composition of submicrometer aerosol</td>
<td>February – May / several minutes</td>
</tr>
</tbody>
</table>
In spring 2015, a field study was carried out to measure the chemical composition of submicrometer aerosol during the Arctic haze period in order to get a detailed picture of the aerosol physics and chemistry. During this study, a Soot Particle Time-of-Flight Aerosols Mass Spectrometer (SP-AMS) was applied. The SP-AMS measures both refractory and non-refractory particulate matter including black carbon, organic aerosols, SO$_4^{2-}$, NO$_3^-$ and NH$_4^+$. The time resolution of the AMS measurements is on the order of about several minutes. Offline sampling of particles with aerodynamic diameters smaller than 10 µm (PM10) was carried out in parallel using a high volume sampler (HVS) with 48 hours time resolution. A fraction of the obtained filter samples were used for elemental carbon (EC) and organic carbon (OC) analysis by applying the thermo-optical method while another fraction was used for off-line high-resolution time-of-flight mass spectrometry (HR-TOF-MS) to obtain detailed information on origin and transformation processes. A list of the applied methods and determined parameters is presented in Table 1.

PRELIMINARY RESULTS

Parameters as black / elemental carbon or particle number of accumulation mode particles show typical seasonal patterns identifying the Arctic haze periods. The time series from the SP-AMS shows that the major component of submicrometer aerosols is SO$_4^{2-}$ (> 50 %) followed by OA (approximately 25 %) (Figure 1). Due to the high concentration of SO$_4^{2-}$ the aerosols observed at VRS appear to be very acidic during the campaign. The relatively high aerosol concentration is consistent with previous findings showing the typical cycle of Arctic haze.

Figure 1. Preliminary chemical composition of the Arctic submicrometer aerosol [µg m$^{-3}$] measured with the SP-AMS from 21 February to 10 April 2015.

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REFERENCES

FORMATION OF HIGHLY OXYGENATED MULTIFUNCTIONAL COMPOUNDS FROM OH- AND O₃-OXIDATION OF α-PINENE UNDER DIFFERENT ENVIRONMENTAL CONDITIONS: UTILIZING POSITIVE MATRIX FACTORIZATION TO DECONVOLUTE CONTRIBUTIONS OF DIFFERENT REACTION MECHANISMS

O. PERÄKYLÄ¹, N. SARNELA¹, C. YAN¹, J. THORNTON², EMMA D’AMBRO², S. SCHOBESBERGER², J. LIU³, J. SHILLING³ AND M. EHN³

¹ University of Helsinki, Department of Physics, 00014 University of Helsinki, Finland
² University of Washington, Department of Atmospheric Sciences, Seattle, WA 98195, USA
³ Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory Richland, WA 99352, USA

Keywords: Secondary organic aerosol, Volatile Organic Compounds, Oxidation, PMF.

INTRODUCTION

Organic compounds are ubiquitous in the atmospheric aerosol (Zhang et al., 2007). A large fraction of this organic material originates from the conversion of Volatile Organic Compounds (VOCs) to less volatile forms by oxidation, and the subsequent condensation of these compounds. This part is called secondary organic aerosol (SOA) (Zhang et al., 2007). Much research in recent years has focused on the formation of SOA from VOCs, but no comprehensive description of its formation exists yet. Recently, Ehn et al. (2014) found that oxidation of monoterpenes, the dominant VOCs emitted by boreal forests, can efficiently form SOA through rapid gas-phase formation and condensation of highly oxidized multifunctional organic compounds (HOMs). To elucidate the formation mechanisms of HOMs, we measured their formation from oxidation of different VOCs as a part of the SOA Formation from Forest Emissions Experiment (SOAFEE) campaign, utilizing the environmental chamber of the Pacific Northwest National Laboratory (PNNL) in Washington state, USA.

METHODS

We investigated the oxidation products formed in monoterpene oxidation under different conditions. These conditions included the initiation of the oxidation reaction by OH radical and ozone, with termination of the radical reactions by HO₂, RO₂ and NO radicals. We measured both the gas and particle phase with a multitude of different instruments, both from the University of Helsinki and from other institutions. The experiments were conducted in a Teflon bag chamber operated in a continuous flow mode, with a residence time of roughly three hours. During the experiments we injected ammonium sulfate seed aerosol into the chamber, along with different VOCs and oxidants. We controlled UV and visible lights separately to alter the photolysis rates of different species, and in this way change the oxidant composition in the chamber.

We measured the molecular compositions and concentrations of different Highly Oxidized Multifunctional organic compounds (HOMs) formed using a nitrate ion Chemical Ionization Atmospheric Pressure interface Time-Of-Flight mass spectrometer (CI-API-TOF, Jokinen et al., 2012). This study focuses on the formation of HOMs under different conditions, as they can readily condense...
to form aerosol. We also measured the concentrations of reactant monoterpenes and concentration of formed aerosol mass, along with measurements of the aerosol size distribution, the volatility of the resulting particles and their activity as cloud condensation nuclei (CCN).

To find out how different reaction pathways contribute to the formation of the hundreds of detected HOMs, we utilize positive matrix factorization (PMF, Paatero and Tapper, 1994). PMF is a factorization technique specially optimized for environmental observations, with the constraint that both the factor profiles and time time series be non-negative. Application of this technique to these measurements will enable us to separate the effects of different oxidants and different termination mechanisms on the formed HOMs.

RESULTS AND CONCLUSIONS

Already without using factorization techniques we found clear differences in the HOMs formed under different conditions. As an example, during ozone oxidation, upon adding NOx to the chamber we observed the appearance of HOMs containing nitrogen, presumably organonitrates. The work on the factorization is still in progress: I will present the results from the factorization in the meeting. We expect the results to further our understanding of the relative contributions of different oxidation pathways to HOM and SOA formation in the ambient boreal atmosphere.

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REFERENCES


ATOMISTIC MODELING OF HETEROGENEOUS NUCLEATION OF ICE

T. PONKKONEN\textsuperscript{1}, O. H. PAKARINEN\textsuperscript{1} and H. VEHKAMÄKI\textsuperscript{1}

\textsuperscript{1}Department of Physics, University of Helsinki, FI-00014, Finland

Keywords: MODELLING, PARTICLE FORMATION, ICE NUCLEATION, MOLECULAR DYNAMICS.

INTRODUCTION

An accurate description of clouds in climate models requires solid knowledge about their properties, but formation of ice clouds, in particular, is not well understood. Ice crystals may form in the atmosphere either by homogeneous or heterogeneous ice nucleation. The latter process, initiated by an aerosol seed particle at relatively high temperatures, is not understood at the molecular level. Different nucleation modes (immersion-, contact- and deposition nucleation) are active in the atmosphere at different temperature and water supersaturation ranges.

METHODS

We have developed an atomistic model of ice crystal formation using a continuum of methods from density functional theory (DFT) to large-scale classical molecular dynamics (MD). We are also looking to calculate single point energies by state of art Local-CCSD(T) methods, as they can handle relatively large systems (~500 atoms) in a reasonable time. We are looking at kinetic and thermodynamic factors controlling nucleation at different conditions and in the presence of different surfaces that represent aerosol particles with varying lattice match with ice, surface corrugation and interactions, both for ideal test systems and for feldspar, AgI and black carbon that are active as heterogeneous nucleation seeds. In particular, we are looking at different nanostructure effects that can lead into large-scale deviation from predictions of classical nucleation theory (CNT), such as unpredicted co-operative effect on surfaces.

CONCLUSIONS

Simulations with the mW potential (Molinero and Moore, 2009) show that surface geometry can largely explain the high nucleation activity of AgI, whereas graphene, representing black carbon which is considered an important particular matter in the atmosphere (Wild et al., 2016), shows very weak activity in mW simulations, without considering the real surface chemistry of the material and ageing effect, studied with DFT.

We also made a comparison of water molecule adsorption on hydroxylated graphene versus pure graphene surfaces to help us understand the difference in nucleation activity between these materials. These comparisons are calculated with quantum chemical DFT and correcting the electronic energy at local Coupled Cluster (CC) level of theory. Accurate results from DFT/CC are compared to MD results and from these we aim to understand better the difference of nucleation activity of different materials. We also show the importance of the edge effect of graphene microstructure – interface between two graphite layers and edge ageing.
Figure 1. Surfaces with a good lattice match with hexagonal ice nucleate ice effectively in MD. This result with the monatomic water (mW) potential shows that the high nucleation activity of AgI can be explained by surface geometry alone, whereas for feldspar the specific surface chemistry of the material needs to be considered. The inset on the right side of the figure shows the surface geometries of the studied surfaces.

Contact nucleation mode simulations show nucleation activity at higher temperatures than immersion, due to the increased mobility and rotational freedom of water molecules at the triple junction at water – vapor – aerosol particle contact line. This explains similar findings in experiments.

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REFERENCES


Highly oxidized molecule formation and contribution to the activation and growth nanocondensation nuclei

P. Roldin1,2, E. Hermansson2,3, D. Mogensen4, F. Söderberg3, S. Smolander1,5, L. Zhou1, A. Rusanen1,6, M. Rissanen1, N. Kivekäs6, E. Swietlicki2, T. Kurten7, M. Ehn1 and M. Boy1

1Department of Physics, University of Helsinki, P.O. Box 48, 00014 Helsinki, Finland
2Division of Nuclear Physics, Lund University, P.O. Box 118, 221 00 Lund, Sweden
3Centre for Environmental and Climate Research, Lund University, P.O. Box 118, 221 00 Lund, Sweden
4Department of Forest Sciences, University of Helsinki, P.O. Box 27, 00014 Helsinki, Finland
5NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, NJ, USA
6Finnish Meteorological Institute, P.O. Box 503, 00101 Helsinki, Finland
7Department of Chemistry, University of Helsinki, P.O. Box 55, 00014 Helsinki, Finland

Keywords: Highly oxidized molecules, gas-phase chemistry, secondary organic aerosol

Introduction
Recent field and laboratory experiments have identified large and rapid formation of Highly Oxidized organic Molecules (HOMs) (Ehn et al., 2014), of which some may be Extremely Low-Volatility Organic Compounds (ELVOCs).

Methods
We have evaluated and constrained the proposed HOM formation mechanism from Ehn et al. (2014) using the Aerosol Dynamics, gas- and particle-phase chemistry kinetic multilayer model for laboratory CHAMber studies (ADCHAM; Roldin, et al., 2014). The mechanism has been implemented into the process-based chemistry transport models ADCHEM (Roldin, et al., 2011). We use different datasets to evaluate: (i) the HOM formation mechanism, (ii) HOMs contribution to nano-condensation nuclei activation and growth, and (iii) how HOMs influences the phase-state and the mass-transfer limited evaporation of SOA particles. ADCHEM was operated as a 1D (vertical column) trajectory model along air mass trajectories reaching the measurement stations Pallas (67.97° N, 24.12° E) and Hytiäliä (61.85° N, 24.28° E). The model results are evaluated using measured particle properties and HOM gas-phase concentrations from CI-API-TOF.

Results and conclusions
With the developed HOM mechanism ADCHEM captures the main features of the observed particle number size distribution evolution during new particle formation events at Pallas field station in northern Finland (Fig. 1a-b). The modelled HOM mass-spectrum is dominated by C10-monomers with between 8 and 11 O-atoms. The modelled concentration of HOM-dimers is very low during the day (< 1 %). During the night typically about 20 % of the HOMs are C20-dimers with 12 to 16 O. A similar diurnal pattern is also present in the measured HOM spectrum at Hytiäliä (Fig. 1c-d). However, in the observations the dimer contribution is about 10 % during the day and 20-30 % during the night. This may indicate that there exists other important HOM dimer gas-phase formation mechanism that the model does not take into account.

Figure 1. a and b shows the modelled and measured median particle number size distributions of 10 new particle formation events at Pallas at 12 am and at 12 pm, respectively. The model results in Fig a-b are from 3 different model cases, with HOM vapour pressures calculated with the SIMPOL functional group contribution method assuming Non-volatile HOMs or no HOMs formation from autoxidation of monoterpenes. Figure c and d shows the modelled and measured average diurnal cycle of the total HOMs C10-monomer and C20-dimer concentrations at Hytiäliä during the 2013 PEGASOS campaign.

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Roldin, P., et al. (2014) ACP, 14, 7953–7993
Roldin, P., et al. (2011) ACP, 11, 5867-5896
INCREASING BLACK CARBON DEPOSITION IN THE EUROPEAN ARCTIC DURING RECENT DECADES

M.M. RUPPEL¹, E. ISAKSSON², J. SOARES³ and A. KORHOLA¹

¹Department of Environmental Sciences, University of Helsinki, 00790 Helsinki, Finland.
²Norwegian Polar Institute, 9296 Tromsø, Norway
³Finnish Meteorological Institute (FMI), 00560 Helsinki, Finland

Keywords: black carbon, deposition, ice core, lake sediments, BC scavenging.

INTRODUCTION

Black carbon (BC) is globally the second most important climate warming agent after carbon dioxide. The warming effects of BC are amplified in the Arctic where its deposition on snow and ice decreases their reflectivity and hastens their melt. Monitoring indicates that atmospheric BC concentrations have declined by 40 % between 1990 and 2009 in the Arctic (Sharma et al., 2013). Furthermore, BC concentrations in snow have not increased from values observed in 1985 to values observed in 2007-2010 (Doherty et al., 2010). Based on these observations and models showing decreasing BC values in the Arctic from the 1960s to the present the AMAP report on BC (2011) suggested that the Arctic seems to have warmed substantially during the last 20 years despite decreasing BC concentrations in the area. However, ca. 90 % of BC is wet-deposited in the Arctic (Wang et al., 2011) and therefore mostly not recorded by atmospheric measurements. The amplified climate effect of BC results from its deposition on high-reflectivity surfaces, and the climate effect of BC in snow is significantly higher than of atmospheric BC (Flanner et al., 2007). Therefore, to comprehensively assess the effects of BC in Arctic climate change, also observations on its deposition in the area are essential. Ice cores and lake sediments represent a valuable means to study BC deposition as they accumulate direct evidence of contamination deposition in chronological order. With information gained from these records the modern atmospheric and snow BC variations can be comprehensively assessed and set into a broader temporal context. Despite the importance of ice core and lake sediment records in deciphering the role of BC in Arctic climate change, relatively few records exist at present.

METHODS

A 300-year ice core from Holtedahlfonna glacier on Svalbard was analysed for elemental carbon (EC, proxy for BC) with a thermal-optical method. As the core reached only 2004 an additional short ice core was collected in 2015 and analysed with the same methodology to confirm whether the EC trend observed in the previous ice core continued at the glacier during the last years. In addition, four lake sediment records from northern Finland each covering ca. the past 150 years were analysed for soot BC (SBC) with a chemothermal oxidation method. Sources for the observed EC trend in Svalbard were investigated with the chemical transport model SILAM.

RESULTS AND DISCUSSION

Unexpectedly, the Svalbard ice core and the majority of northern Finland lake sediment records show a pronounced increase in BC deposition from ca. 1970 to the present (Fig. 1., Ruppel et al., 2014, 2015). Also the shallow ice core covering the last ca. 15 years indicates continued increase in BC concentrations and deposition at the Svalbard glacier. Model results support the inference that the EC deposition increase in Svalbard may be caused by increased BC scavenging efficiency due to increased temperatures since 1980, despite decreasing atmospheric BC concentrations. The trend indicated by the lake sediments is more likely caused by regional emissions from the Kola Peninsula.
Figure 1. EC deposition to the Holtedahlfonna ice core compared to standardized SBC fluxes to the Finnish lake sediments. A) EC deposition in mg m$^{-2}$ yr$^{-1}$, with 10-year running averages (red line). B) Stacked SBC fluxes at the lakes expressed as standard deviations from the mean. A LOESS smoother (black curve) is fitted to the data. The sediment records were standardized to avoid any single record dominating the general trend.

CONCLUSIONS

The climate impact of BC may have increased in the European Arctic during the last decades. Inclusion of BC deposition records in future comprehensive evaluations of the Arctic climate effect of BC is essential. The model results show that BC deposition trends cannot be estimated solely based on atmospheric BC observations in the Arctic where wet deposition dominates over dry-deposition.

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REFERENCES

Sea spray aerosol (SSA) particles are hygroscopic - they readily exchange moisture with their surroundings, and therefore they change their equilibrium water content and radii under different atmospheric conditions. This influences their role in chemical reactions and the rate at which they uptake gases, as well as their light-scattering properties. To date, the growth of a SSA particle above 70% relative humidity has been considered to be very close to that of NaCl. However, using a laboratory sea spray chamber we have observed that inorganic SSA particles have a significantly lower hygroscopicity than NaCl. We report these measurements alongside simulations using large-scale models designed to test the sensitivity of radiative forcing to the hygroscopicity of SSA. These highlight that the lower hygroscopicity we observe has important implications for calculations of the radiative balance of the Earth given that most models currently use NaCl as a model for inorganic SSA hygroscopicity.

1Department of Environmental Science and Analytical Chemistry, Stockholm University, 106 91 Stockholm, Sweden

2Paul Scherrer Institute, Laboratory of Atmospheric Chemistry, 5232 Villigen, Switzerland

3Department of Meteorology, Stockholm University, 106 91 Stockholm, Sweden

4Royal Institute of Technology, 100 44 Stockholm, Sweden

5University of Eastern Finland, FI-70211 Kuopio, Finland

6Department of Physics and Astronomy, Uppsala University, 751 20 Uppsala, Sweden
ARCTIC AEROSOLS AND THEIR COMPOSITION IN NORTHERN GREENLAND

N. SARNELA¹, H. JUNNINEN¹, L. AHONEN¹, T. JOKINEN¹, J. MIKKILÄ¹, O. PERÄKYLÄ¹, D. WIMMER¹, T. PETÄJÄ¹, H. SKOV²,³, M. KULMALA¹ AND M. SIPILÄ¹

¹ University of Helsinki, Department of Physics, P.O. Box 64, 00014 University of Helsinki, Finland.

² Department of Environmental Science, Aarhus University, Roskilde, Denmark.

³ University of Southern Denmark, Institute of Chemical Engineering and Biotechnology and Environmental Technology, Odense, Denmark.

Keywords: atmospheric aerosols, Arctic research, mass spectrometry.

INTRODUCTION

The Arctic environment is known to be especially sensitive to global warming and clouds are in the key role of radiative balance of the Arctic environment (Garrett et al., 2002). New particle formation is a process where molecular clusters form from atmospheric vapours by condensation and/or chemical reactions. Later the clusters can grow into larger particle sizes and act as cloud condensation nuclei. New measurement techniques have enabled studying even the first steps of new particle formation. In previous studies sulphuric acid (Sipilä et al., 2010) and oxidized organic compounds (Ehn et al., 2014) have been seen to be responsible of new particle formation. Until recent years the composition of newly formed particles has not been studied in the Arctic. Since there is little if any vegetation in the Polar Regions the organics are not likely to play a significant role in particle formation. Instead there has been observed iodine during new particle formation events (Allan et al., 2015). We conducted a six month measurement campaign in the Arctic aiming to get more insight into new particle formation and nucleation processes in the Arctic.

MEASUREMENT CAMPAIGN AND INSTRUMENTATION

We conducted an intensive measurement campaign called Nordic Center of Excellence “Cryosphere atmospheric Interaction in a Changing Climate (CRAICC)” in Villum research station in Northern Greenland (81° 36'N 16°39’W, Fig. 1). The campaign started in mid-February 2015 and was going on until the end of August 2015.

The Villum research station has continuous measurements of meteorological parameters, ozone concentration and particle size distribution of 10 – 900 nm (with Scanning Mobility Particle Sizer). During the CRAICC measurement campaign we had nitrate-CI-API-TOF (Chemical Ionization Atmospheric Pressure interface Time-Of-Flight mass spectrometer, Jokinen et al., 2012) to measure extremely low volatility vapours such as sulphuric acid and molecular clusters. We used acetate-CI-API-TOF to measure low volatility vapours such as formic acid. Ambient ions were measured with API-TOF. Particle concentrations of 0.8 – 40 nm particles were measured with Air Ion Spectrometer (AIS, Mirme and Mirme, 2013), sub-3 nm particles were measured with Particle Size Magnifier (PSM, Vanhanen et al., 2010) and the particle composition was measured with an Aerosol Mass Spectrometer (Canagaratna et al., 2007).

PRELIMINARY RESULTS

The measurement campaign was successful and we got data from the whole over six month period. The aerosol particle concentrations were generally low during the measurement campaign, but occasionally we observed elevated particle concentrations and some particle growth events. Also sub-3 nm particle concentrations were observed during these events. We classified the days into three groups according to the particle size distribution between 2-20nm (Figure 1.).
Figure 1. Classification of the days into groups according to the particle size distribution between 2-20nm

The measured vapour concentrations varied between spring and summer time. We detected high concentrations of iodic acid in late spring (April – May) when the solar radiation was more intense. During the summer time the snow started to melt and the iodic acid concentrations decreased. According to the preliminary analysis, it seems that the composition of particles was different during the spring and summer time. It appears that iodine oxides are important in the spring time particle formation. We observed iodine oxide clusters that are similar that have been seen during particle events in coastal site in Ireland (Sipilä et al., 2016, in review). These results support the results of Allan et al. who detected iodine in Arctic aerosols larger than 30 nm but this is the first time that iodine oxide has been seen in molecular clusters in the Arctic. When the snow started to melt the role of iodine oxides in the particle formation seemed to decrease and the role of sulphuric acid increased. The data analysis is still in progress and we are going to further examine these results.

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REFERENCES

Canagaratna, M. R. et al. (2007) Chemical and microphysical characterization of ambient aerosols with the aerodyne aerosol mass spectrometer, Mass Spectrometry Reviews, 26, 185.
ASSESSMENT OF BLACK CARBON IN ARCTIC: REFINEMENT OF THE CHEMICAL TRANSPORT MODEL SILAM

J. SOARES¹, J. STRÖM², J-C. GALLET³ and M.SOFIEV¹

¹Finnish Meteorological Institute (FMI), 00560 Helsinki, Finland
²Department of Environmental Science and Analytical, Stockholm University, 11418 Stockholm, Sweden
³Norwegian Polar Institute, 9296 Tromsø, Norway
⁴Department of Environmental Sciences, University of Helsinki, 00790 Helsinki, Finland.

Keywords: black carbon, chemical transport modelling

INTRODUCTION

Black carbon (BC) is an important climate forcer, in particular over the Arctic. The absorption of radiation caused by BC-containing aerosols over a highly reflective surface, such as snow, will result in a warming at high-altitudes (haze layer) and will warm the surface due to an increase of the downward longwave radiation. In snow, BC will intensify the melting of the snow pack. Based on observations and model results, atmospheric BC concentrations have declined in the Arctic, during the last decades (AMAP, 2011). With BC being mainly wet-deposited in the Arctic (Wang et al., 2011), the warming of the atmosphere in the last decades resulted in an increasing of wet deposition and, consequently, increasing BC concentration in snow as reported in core measurements in Svalbard, Norway (Ruppel et al., 2014). Chemical transport models (CTM) represent more accurately the atmospheric composition closer to sources than in remote places, such as the Arctic. Multi-model studies show a discrepancy between models towards northern latitudes (e.g. Eckhardt et al., 2015). Stohl et al. (2013) shows a misrepresentation of emissions for atmospheric composition in the Arctic. The goal of the study is to bring new insight on the BC chemical transport modelling by refining the CTM developed by the Finnish Meteorological Institute: SILAM.

METHODS

The refinement of the SILAM model was achieved by improving and complementing already existing emission databases (MACCity (Granier et al., 2011) and ECLIPSE (Granier et al, 2011)) and by describing more accurately BC properties, ageing via OH oxidation (Liú et al. (2011) and removal processes (e.g. in-cloud scavenging) based on measurements performed at the Zeppelin Station, Norway. The validation of SILAM, via concentration and deposition measurements, close to BC sources and in remote places (Arctic sites) was done for 2010.

RESULTS AND DISCUSSION

The results show that the model represent more accurately the surface concentrations when driven by emissions which include flaring in Russia, ECLIPSE dataset (Figure 1a,b). Changing particle size distribution for a smaller size distribution (mean $D_p$ from 1.5 to 0.5 um) results that the transport of BC is lengthier and increases surface concentrations predicted by the model, though it can have in very specific cases the opposite effect, tendency to happen when the plume hitting the station is mainly due to domestic heating. Adding ageing of the aerosol to SILAM does not bring further improving to the model results (Figure 1c,d).

CONCLUSIONS

The refinement of SILAM to model BC is an ongoing process. The first steps of the refinement have already proven to improve models results when modelling Arctic sites.
Figure 1. Validation of model results with surface concentration observations (OCug m$^{-3}$) at Zeppelin site, Norway, for 2010: timeseries and scatter plots assuming different emission datasets (a,b) and mean $D_p$ and ageing (c,d)

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REFERENCES


COMPARISONS OF FIELD EXPERIMENTS OF SOOT’S EFFECT ON NATURAL SNOW AND AMBIENT MEASUREMENTS

J. SVENSSON1,2, A. VIRKKULA1,3, O. MEINANDER1, N. KIVEKÄS1, H.-R. HANNULA4, A. HEIKKILÄ1, A. KONTU4, P. DAGSSON-WALDHAUSEROVA3,6, J. PELTONIEMI1,3, K. NEITOLA1, D. BRUS1, M. GRITSEVICH7,3, A. HIENOLA1, G. DE LEEUW1,3, and H. LIHAVAINEN1

1Finnish Meteorological Institute, Helsinki, Finland
2Department of Environmental Sciences, University of Helsinki, Helsinki, Finland
3Department of Physics, University of Helsinki, Helsinki, Finland
4Arctic Research Center, Finnish Meteorological Institute, Sodankylä, Finland
5Faculty of Environment, Agricultural University of Iceland, Hvannmyri, Iceland
6Department of Physics, University of Iceland, Iceland
7Finnish Geospatial Research Institute, Masala, Finland

Keywords: Black Carbon, Snow Albedo.

INTRODUCTION

Snow is the most natural reflective medium on Earth with a typical albedo of ~0.8 for fresh snow. Thus, it plays a very important role in the radiative balance of snow and ice covered areas around the globe. Snow albedo is modified by many parameters, including the snow’s physical properties (e.g. snow grain size and thickness). Additionally, the presence of light-absorbing aerosols in the snow can also have an effect on albedo and consequent snow melt (e.g. Warren and Wiscombe, 1980). Soot particles, containing black carbon (BC) and organics, is a light-absorbing aerosol that is produced by the incomplete combustion of fossil and bio fuels.

Experiments dealing with soot’s effect on the cryosphere have to this date been limited to a few reported studies (Conway et al., 1996; Brandt et al., 2011; Hadley and Kirchstetter 2012). Here we present some experiments carried out in 2011 and 2013 (Soot on Snow experiments, SoS) dealing with these matters, and compare our experimental results with the laboratory study of Hadley and Kirchstetter (2012) and the work of Pedersen et al. (2015).

METHODS

The first experiment (SoS2011) was conducted at a private farming field in Nurmijärvi, southern Finland, March – April 2011. The second experiment (SoS2013) was conducted at the Sodankylä airfield near the FMI Sodankylä observatory, Finnish Lapland, April – May 2013. Soot was deposited with different methods onto the snow surface in the experiments. In SoS2011 soot particles were produced by burning various organic materials (wood and rubber pellets from used tires) in a wood-burning stove. The smoke was lead through a pipe, cooled by snow surrounding the pipe, and lead into a rectangular chamber situated on top of the snow. A different approach to deposit the soot was taken in SoS2013. Soot was acquired beforehand from a chimney-sweeping company in Helsinki, which collected the soot from residential buildings with small-scale wood burning. The soot was blown into in-house made cylindrical chamber (diameter of 4 m) carefully installed on top of the snow. The blowing system consisted of a blower, a tube blowing air into a barrel filled with the soot, and a cyclone removing particles larger than about 3 µm. After soot deposition to the snow, pyranometers were installed at the sites to measure incoming global radiation and reflected radiation. Snow samples were also collected and analyzed for elemental carbon (EC) with a Sunset Labs EC/OC analyzer (here EC is used as a proxy for soot). Further, the snow physical characteristics were measured (including thickness, hardness, grain shape and size).

RESULTS AND CONCLUSIONS
The effects of soot on snow were visible in our experiments. The albedo of the soot contaminated snow decreased more compared to the clean reference snow. The physical characteristics of the snowpack also changed when comparing the sooted snow to the clean reference snow.

Our experimental data from the SoS campaigns is compared to the work of Hadley and Kirchstetter (2012) and Pedersen et al. (2015) in fig. 1. The data from Hadley and Kirchstetter (2012) contain snow with different grain sizes and the corresponding EC concentrations, whereas Pedersen et al. (2015) is based on ambient measurements of snow albedo and EC concentrations. The SoS data generally agree with these studies, although not as well comparing to the larger snow grain sizes used in Hadley and Kirchstetter (2012). This is probably due to the fact that their laboratory study had different light conditions compared to SoS where no artificial light was used.

![Graph showing albedo as a function of EC concentration in the snow](image)

**Figure 1.** Albedo as a function of EC concentration in the snow. Circles are experimental data from SoS2013 and SoS2011, with the average solar noon albedo and corresponding EC concentrations. Black lines represent fittings of $\text{Albedo} = \beta \text{EC}^c + d$ to the experimental data including and excluding the darkest spot of SoS2011. The red lines are based on the work of Pedersen et al. 2015, and the blue shapes the laboratory work of Hadley and Kirchstetter 2012 with different snow grain radii.

**ACKNOWLEDGEMENTS**

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REFERENCES


COMBINING CCN ACTIVATION AND HYGROSCOPIC GROWTH OF ANTHROPOGENIC SOA PARTICLES

C. WITTBOM¹, S. SJOGREN¹,⁴, J. RISSLER², A.C. ERIKSSÖN², P. ROLDIN¹,³, E.Z. NORDIN², P.T. NILSSON², E. SWIETLICKI¹, J.H. PAGELS² and B. SVENNINGSSON¹

¹ Department of Physics, Lund University, P.O. Box 118 SE 221 00, Lund, Sweden
² Ergonomics and Aerosol Technology, Lund University, P.O. Box 118 SE 221 00 Lund, Sweden
³ Department of Physics, P.O. Box 48, University of Helsinki, 00014, Finland
⁴ University of Applied Sciences Northwestern Switzerland, Brugg-Windisch, Switzerland

Keywords: CCN, gf, SOA, insoluble.

INTRODUCTION

Hygroscopicity measurements of secondary organic aerosols (SOA) can show discrepancies between the super- and subsaturated regimes, which cannot readily be explained by instrumental differences. The particles often show a better activity as cloud condensation nucleus (CCN) than indicated by measurements of the hygroscopic growth. Here, the discrepancy between the two regimes has been investigated using data from measurements in the Lund University (LU) aerosol laboratory smog chamber.

METHODS

Cloud-activation and hygroscopic properties of photochemically processed anthropogenic aerosols were monitored using the Cloud Condensation Nuclei Counter (CCNC, DMT-100, SFCA protocol) in conjunction with the Hygroscopic Tandem Differential Mobility Analyser (H-TDMA) at 90% relative humidity (RH). Also, a Differential Mobility Analyser-Aerosol Particle Mass Analyzer (DMA-APM; Kanomax Japan 3600), with a thermodenuder introduced between the DMA and APM, was used for characterization of the particle mass-mobility relationship. Measurements in the H-TDMA, CCNC and APM were performed after size selection by a DMA, according to the mobility diameter ($d_m$). To determine the chemical composition of the non-refractory species (i.e. the organic aerosol, OA) in the particles an online Aerodyne high-resolution time-of-flight mass spectrometer (HR-ToF-AMS, Aerodyne Research) was used. A custom-built scanning mobility particle sizer (SMPS) measured the particle number size distribution.

Results from five types of anthropogenic aerosols, have been the basis for the study: (1) exhaust from a diesel-powered passenger vehicle, (2) a flame soot generator, (3–4) exhaust from gasoline-powered vehicles and (5) a precursor experiment. Ammonium sulphate (AS) particles were used as seed for aerosol type 3–5. Selected amounts of the anthropogenic secondary organic aerosol (SOA) precursors, toluene and m-xylene, were added to aerosol type 1, 2 and 5. All aerosol types were photo-chemically aged using ozone and UV-light in a Teflon bag. For details regarding the instrumental set-up and aerosol types, see Nordin et al., 2013 and Wittbom et al., 2014.

CONCLUSIONS

Preliminary modelling results show that one explanation for the discrepancy between the two regimes can be attributed to solubility limitations of the organic material condensing onto the particles during the photochemical processing. Accounting for a reduction in solubility affects the hygroscopic growth at sub saturation in a larger extent than the CCN activation, while comparing the results for infinitely soluble ($i$) with the limited soluble ($ii$) mass fraction organic ($mf_{org}$) in Fig.1.
Figure 1. Measurements of $s_c$ and $gf$ are compared with modelling results when (i) the organic fraction is infinitely soluble and (ii) when solubility limitations are taken into account. The organic mass fraction is indicated by colour and the mobility diameter ($d_m$) by size of the circle. Soot aerosols (1-2) are circles, and gasoline aerosol (3-4) and precursor aerosol (5) measurements are indicated by crosses behind the circles.

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REFERENCES


Investigation of the climate impact on the snow and ice thickness in Lake Vanajavesi, Finland

Yu Yang1, Matti Leppäranta2, Bin Cheng3, Zhijun Li4
1Department of Basic Sciences, Shenyang Institute of Engineering, Shenyang 110136, China
2Department of Physics, University of Helsinki, Fi-00014 Helsinki, Finland
3Finnish Meteorological Institute, Fi-00101 Helsinki, Finland
4State Key Laboratory of Coastal and Offshore Engineering, Dalian University of Technology, Dalian 116024, China

Keywords: Lake snow and ice, climate impact, air temperature, surface balance.

INTRODUCTION

A one-dimensional high-resolution thermodynamic snow and ice model (HIGHTSI, Launiainen and Cheng, 1998; Cheng et al., 2003, 2008) was applied for Lake Vanajavesi (61.13°N, 24.27°E), located in southern Finland (Fig. 1). This model contains congelation ice, snow-ice and snow layers with full heat conduction equation. Atmospheric forcing was derived from weather observations and climatology, which also drove the snow cover evolution. The simulation results were compared with measured ice and snow thickness. Ice climatology was examined for the 30-year period 1971-2015, forced by daily weather observations; also the correlation between the observed monthly total precipitation and snow accumulation was investigated in order to understand the uncertainties of precipitation as model forcing for climatological simulation.
A number of climate sensitivity simulations were carried out for the ice season. The objectives of the present work were to assess the applicability of the HIGHTSI model for lake snow and ice thermodynamics, to find out the most important factors affecting lake ice growth and melting, and to evaluate the influence of climate variations on the lake ice season.

DATA

Synoptic-scale weather conditions and regional climate over this area are represented by Jokioinen meteorological observatory (60.8°N, 23.5°E; WMO station 02863), located some 50 km southwest of Lake Vanajavesi (Fig. 1). The weather forcing data for the lake ice model consist of wind speed (Va), air temperature (Ta), relative humidity (Rh), cloudiness (CN) and precipitation (Prec), collected at three-hour time intervals. The winter 2008-2009 was mild (Fig. 2).

CONCLUSIONS

The ice season 2008-2009 lasted four months. Model simulations were started up in the beginning of January from the initial snow and ice thicknesses of 0.5 cm and 2 cm, respectively. The simulated snow thickness agreed well with the observations (Fig. 3).
Overall, lake-ice processes are closely associated with weather conditions from autumn through spring. The freezing of lake surface largely depends on the lake heat storage and the cooling rate of the air temperature during the autumn. Ice breakup can be explained mainly by the net solar radiation (e.g. Leppäranta, 2009). Fig. 4 shows a comparison of the results of the HIGHTSI simulations using climatological forcing (Table 1), with the air temperature artificially shifted by ±1°C or ±5°C. Compared to the reference run, shifting by ±1°C may lead to about 5 days change of freezing date and 8 days change of breakup date. These values are close to 5 days for both dates, obtained by linear regression on lake phenology time series for lakes in southern Finland (Palecki and Barry, 1986). The breakup date seems to be more sensitive to the air temperature in the model.

Figure 3. Time series of observed and modelled snow and ice thickness. The dark gray line and the asterisk are the observed snow thickness in Jokioinen and on Lake Vanajavesi, respectively. The black dashed and solid lines are modelled snow and ice thickness (reference experiment), respectively. The circles are the observed average ice thickness and the spatial standard deviation is indicated by the vertical bar (Lei et al., 2011).

Figure 4. Model sensitivity to the air temperature level. The black solid line is the reference (present climate). The gray solid (dashed) line and the light gray solid (dashed) line are modelled ice thickness based on the air temperature decreasing (increasing) 5°C and 1°C, respectively.

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REFERENCES